METALLURGY OF CAST IRON.

A COMPLETE

EXPOSITION OF THE PROCESSES INVOLVED IN ITS TREATMENT, CHEMICALLY AND PHYSICALLY, FROM THE BLAST FURNACE THROUGH THE FOUNDRY TO THE TESTING MACHINE.

BY

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PREFACE.

This work is written with a view to its value not only to the founder, the moulder, the blast furnaceman and the mechanical engineer, but also to the designer, the draftsman, the pattern-maker, the college specialist, and all that may in any manner be desirous of obtaining a practical knowledge of cast iron in its application to founding or any allied interests.

In compiling this volume, the author has been guided by a broad experience as a moulder and founder in loam, dry and green sand work, in the various specialties of founding, all of which require a knowledge of the subject as a whole in order to arrive at correct conclusions on questions pertaining to cast iron.

A factor which has also aided the author in presenting this volume is that of being for the past five years surrounded, in his present foundry location, by blast furnaces, thus affording him every opportunity of making a close study of modern furnace methods and the principles involved in making iron. This has also enabled the author, as a foundryman, to determine wherein many principles involved in furnace practice can often be well utilized in constructing and operating cupolas, as well as in mixing iron.

In many respects this work will be found to be in advance of general practice, presenting many new subjects, principles and ideas calculated to greatly broad-

en practical literature upon the metallurgy of cast iron, but the author does not advocate any measures that have not been thoroughly tested by experience, or a close study of the subjects presented. While this work will be found largely the product of the author's own experience and research, he has also drawn upon the work of others, wherever in his judgment this could in any way prove of practical value in giving a completeness to the various subjects treated.

The work will be found to contain many appliances which the author has originated and upon which he could have secured patents, thereby greatly advancing his pecuniary interests, but believing the advancement of founding is best aided by their being given freely to any that desire to use them, all are at liberty to freely utilize the various improvements shown.

About a dozen of the chapters are revised extracts of papers which were presented by the author before the British Iron and Steel Institute, the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the Eastern and Western Foundrymen's Associations. The leading trade papers of America and Europe are also to be credited with having given first publicity to some of the author's writings herein presented. Among those to be mentioned are the *American Machinist*, the *Iron Age*, the *Iron Trade Review*, *Foundry*, among American publications, and *Engineering*, of London, *The Engineer*, of Glasgow, and other leading trade papers of Europe. To all these associations and trade papers the author tenders his thanks. The encouragement thus rendered has served to stimulate the completion of this work. The task in hand has taken about four years to

compile, due to the experiments, research, etc., found necessary in order to advance the original information presented. The result has been to bring all the author's writings on the various subjects treated under one cover, giving to the reader an advantage that could not be otherwise attained.

This work is divided into four parts, the first being an original treatise illustrating the principles involved in a general way in the making of iron, commencing with a very complete chapter on coke and its kin, iron ore, followed by a description of furnace methods and principles which can often be well applied to cupola practice.

The second part treats of the advancement of cupola practice, showing the latest and best improvements. It illustrates all the known methods for the application of "center blast," accompanied with information on cupola practice necessary to be used with the author's first two volumes to give a complete presentation of the subject up to date.

The third part of this work is given up to the advance and necessity of chemistry in founding, and clearly illustrates the requirements of a wholly different practice than has been followed up to a year or two ago by most founders, namely, of judging pig iron for mixture by its fracture, a quality which chemistry has proven to be wholly impractical. It shows the founder following such methods how he cannot expect to meet with other than bad, unaccountable results, as well as heavy losses. It teaches how the greatest possible economy and desired ends in making mixtures are best achieved. It also defines, for practical application in the various specialties, the affinity which one

chemical property or metalloid has for another in changing the character or grade of iron, and discloses valuable information on the science of mixing and melting cast iron.

The fourth part of this work is devoted to the subject of testing, and discloses new discoveries which explain causes for erratic results heretofore obtained for the most part from transverse and tensile tests, contraction chill, etc., recorded from bars of like area poured from the same ladle and gate, and presents methods best calculated to reduce erratic results to the least possible minimum.

Following the seventieth chapter, the work is closed with a few tables and an index. The first table gives the net weight of pig iron in gross tons of 2,268 pounds, ranging from one to one hundred tons. The second table presents the full names of chemical properties in metal, accompanied with their abbreviations or symbols as generally written by chemists. The tables following are copied from Messrs. Cremer and Bicknell's "Handbook for Chemical and Metallurgical Practice."

It is not intended that this preface shall convey a complete statement concerning the importance of all the subjects treated. In order to obtain a fuller conception of the important points discussed in the various parts of the work, the reader is kindly referred to the introduction prefacing each section.

THOS. D. WEST.

SHARPSVILLE, PA., Jan. 5, 1897.

PART I.

CHAPTER I.

COKE FOR THE FURNACE AND FOUNDRY.

The first successful use of coke for smelting in a blast furnace is described by Dr. Percy in his work * as being done by Abraham Darby, at the Coalbrookdale Iron Works, Shropshire, Eng., between 1730 and 1735. The news of this success spread to America where, in 1841, two carpenters, Province McCormick and James Campbell, in company with John Taylor, a stonemason, on a farm by the Youghiogheny River, Pa., experimented with oven coke; but it awaited the Clinton Furnace, at Pittsburgh, Pa., in 1860, to demonstrate the great value of coke as a furnace and cupola fuel.† At this time, anthracite, bituminous coal and charcoal constituted the chief fuel used, the former being that employed most wholly for melting in cupolas.

In changing from anthracite to coke for foundry work, Pennsylvania and Ohio took the lead, and it was not long ere its use increased to such a degree that few places in the country are now found using coal wholly as a fuel for melting. Coke has forced its adoption mainly from being a cheaper fuel, requiring less blast and melting more quickly than coal, but the

* Metallurgy of Iron and Steel, page 888.

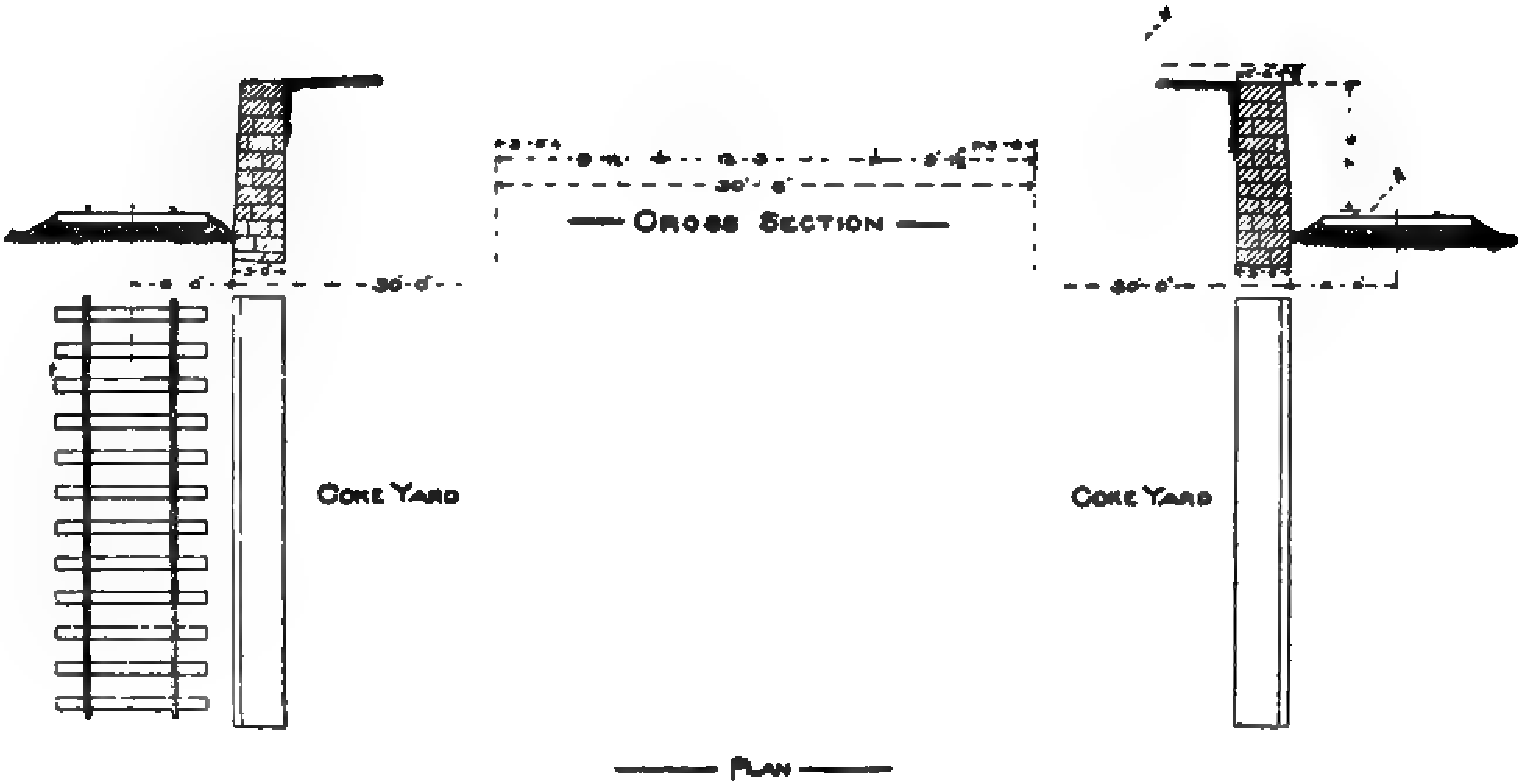
† Tenth Census of the United States, Vol. 10, p. 23.

latter has also still some advantages; and owing to the fact that chemical and physical properties of the fuel have much to do with the character of cast iron when made or remelted, the writer has thought a general article on this subject would be of interest to all.

The process of making furnace and foundry coke simply consists in taking soft or bituminous coal, which generally resembles that used for firing boilers to raise steam, and letting it burn in a smoldering fire for 48 to 72 hours in what are called coke ovens, generally of the form seen in Fig. 1. Other methods and forms than that shown in the illustration are used, and some of them are covered by patents, the advantages claimed for them are in the recovery of by-products, in obtaining high carbon in the coke, eliminating sulphur and other impurities in the form of phosphorus, hydrogen, oxygen and nitrogen, also in saving labor and obtaining a large yield of coke from the coal. France and Germany have done much to perfect the coking of coal. It is said that progress in this line is chiefly due to them and that they have the best methods in coking. To have personal knowledge of the process of coke-making, the writer paid a visit to some ovens to observe the actual workings of those of the bee-hive type, and was well paid for the time spent in the trip, as it afforded a clearér idea of operations than anything he had read.

Coke has its chemical and physical qualities, as iron has, and conditions in coking coal cause a great diversity in both the physical and chemical composition. The chemical qualities desirable in coke are: first, that it be low in sulphur; second, that it be high in carbon, and third, that it be low in ash.

FIG. 1.—BENCH



The evil of having high sulphur in coke often leads to very serious results in founding as well as in furnace work, owing to the great affinity which iron has for sulphur. It is very essential in coking coal that plenty of pure water be had. A drought can make water so scarce, that what little runs over the hills, or comes from wells, will absorb sulphur from the ground and carry it to the coke. An experience of this character in the year 1894 affected most of the furnaces and foundries using Connellsville coke, and the writer's foundry suffered losses from this cause. As a general thing, the coal from which coke is made contains more sulphur than the coke. The process of coking has much to do with the percentage of sulphur in the product. Coke from the same coal and oven can and often does vary greatly in percentages of sulphur. There are many conditions affecting this.

To test the sulphur contained in coke a chemical analysis is often advisable. If sulphur is above .90, it can often be told by the odor of the escaping gases and the stifling fumes a cupola will emit, as compared with coke below .80.

The carbon in coal is more or less volatilized or lost in the process of coking the coal. It is natural to expect such results, as fire consumes carbon; and coal cannot be coked without being brought up to a state of incandescence or fusing heat. The carbon found in coke, compared with that which existed in the coal, generally ranges from 70 to 90 per cent., although by the utilization of some of the patent ovens it is claimed that practically little or no carbon will be lost in coking the coal. In coke, the carbon exists as "fixed carbon" and the greater amount of fixed carbon coke

contains the better its fusing qualities or the more calories of heat will it diffuse, all other conditions of melting being equal. Coking largely expels the volatile matter, and the fixed carbon that remains is of a far more porous character than in the form of coal or as taken from the earth. Mainly for this reason carbon in coke is more effective in insuring rapid melting and at the same time requiring less pressure of blast than coal. The tendency of coal when fusing in a stove, furnace or cupola is to form a mass, rendering it much more difficult than coke to penetrate by air or blast. Since this discovery, the use of coke has extended from the day of its introduction. The production in the United States reached the enormous total of 12,010,829 gross tons in 1892, and in each of the two following years ranged between 9,000,000 and 10,000,000 tons. Coke has largely displaced anthracite and bituminous coal in reducing ores, melting steel and iron and alloys, and its domestic use has also largely increased. The fixed carbon in coke used for furnace and foundry work generally ranges from 80 to 90 per cent. Some shipments may go under this 10 to 20 per cent., while others will exceed it two to five per cent.

Carbon and ash are the two chief components of coke. The ash is an impurity which, like hydrogen, oxygen, phosphorus, nitrogen and sulphur, lessens the commercial value of coke, as the percentages increase. The ash in coke for furnace and foundry coke generally ranges from 10 to 14 per cent. It may exceed this by two to four per cent. or go as low as only five per cent. The ash of a coke is generally meant to include all the above-mentioned impurities, unless the deleterious qualities are separately specified, as in the

following analysis (Table 1) of an ash, by Mr. E. C. Pechin:

TABLE I.—ANALYSIS OF ASH IN CONNELLSVILLE COKE.

Silica	5.413
Alumina	3.262
Sesquioxide of iron	0.479
Lime	0.243
Magnesia	0.007
Phosphoric acid	0.012
Potash and soda	Traces.
	9.416

Silica and alumina are the chief components of ash in coke, and many in defining ash only cite these two elements and class the others as independent impurities. The less ash coke contains, the greater is its value, generally speaking, although very low ash is not desirable in all cases. It is often beneficial in assisting the formation of a good slag, and is essential in giving silicon to iron, as seen below. There is no question but that it is a benefit to know the percentage of ash, as well as of carbon or sulphur, as then such knowledge will assist in economically and properly fluxing a furnace or cupola. Coke made from washed coal will generally contain less ash than that from unwashed coal.

The amount of silica in fuel is what largely determines the amount of silicon found in iron. The higher the silicon required the more fuel necessary to be used in a furnace. The silica generally ranges from 5 to 6 per cent. in coke. For further notes on silica in making iron, see page 31.

Coke for commercial purposes is classed either as "gas coke" or "oven coke." The former is obtained from the retorts used in gas works to produce illumi-

nating gas or from the retorts used in manufacturing coal tar, oil and other by-products. Some kinds of coal will produce gas coke by which iron can be melted. Coal of a quality obtained in the Connellsville region is suited for producing gas house coke, which will melt iron. Wherever gas coke is utilized for melting iron much more of it must be used than of oven coke and at its best it is an undesirable fuel for this purpose. For drying molds or cores it will often give good satisfaction and work better than hard coke, but more of it must be generally used than of oven or hard coke, to furnish the same number of calories.

Oven coke is the variety demanding the attention of the founder. Its physical properties are quite as important to be understood and followed up as its chemical properties, to secure good results in melting iron or reducing ores. Oven coke can be light and porous as well as dense and heavy. It is spoken of also as hard or soft. The terms hard and dense do not mean the same thing. Coke can be dense but soft, so that its power to resist a crushing load is greatly impaired.

The question of density is largely one of cell space, and in hard as well as soft coke these cells may be of a character that does not permit air or gas to pass freely through the body. Oven coke is generally considered to have a cell structure about 50 per cent. greater than exists in the coal. The quality of hardness is one of much importance, especially in blast furnace practice, as the coke should possess a certain strength to sustain the weight of the stock which is charged on top of it. If it is not strong enough to resist the load, it will be crushed into a mass so compact in its body as to prevent passage of blast through it in

the way necessary to create proper combustion, or raise the temperature of the furnace to a heat which will cause it to work well. And to a degree the same may be said of cupola work. The following Table 2 of physical tests by Mr. John Fulton will be of interest at this point to illustrate the crushing strength of coke, with other properties. Accompanying the same is given a chemical analysis of the same coke by Mr. A. S. McCreath and Mr. T. T. Morrell:

TABLE 2.—PHYSICAL TEST OF SEVENTY-TWO-HOUR COKE.

Locality.	Grams in one cubic inch.		Pounds in one cubic foot.		Percentage.		Compressive strength per cubic inch ¼ ultimate strength.	Height of furnace charge supported without crushing.	Order in cellular space.	Hardness.	Specific gravity.
	Dry.	Wet.	Dry.	Wet.	Coke.	Cells.					
Standard coke, Connellsv'le	12.46	20.25	47.47	77.15	61.53	38.47	284	114	1	3.5	1500
Walston	16.63	23.4	63.36	89.15	71.07	28.93	270	109	1	3.7	1900

TABLE 3.—CHEMICAL ANALYSIS.

Locality.	Fixed Carb.	Mois.	Ash.	Sulph.	Phos.	Volatile matter.
Standard coke, Connellsville	87.46	0.49	11.32	0.69	0.029	0.011
Walston coke, (A. S. McCreath 72-hour coke)	88.476	.148	9.731	.951	.008	.692

The above Tables 2 and 3 are taken from a most excellent article written by Joseph D. Weeks, of Pittsburg, which appeared in the Pennsylvania Annual

Report of the Secretary of Internal Affairs, 1893. In referring to the analysis of the coke tested, Mr. Fulton, who furnished the analysis, says: "These tests show a compact, hard-bodied coke, harder than the average Connellsville standard. This coke has been carefully prepared and cannot be distinguished from Connellsville coke. The cells are a little less than the Connellsville, but the difference is not large enough to induce any marked change in blast furnaces. It has proved an excellent fuel for this and kindred uses."

"Silvery bright metallic lustre coke," possessing a solid hard body, with cells well connected and of a uniform structure, can generally be called "good coke." The hidden element that might exist to do serious harm in such a grade of coke is sulphur, for this can be high or low in any grade of coke. The shipment generally condemned by the founder or furnaceman is small-sized coke mixed with coke dust, or coke that is dark in general appearance and soft in quality. Even when a coke has all the other commendable qualities but is in small pieces, this fact is often sufficient to produce bad results in smelting or melting, especially so in the latter. A coke may not possess that much-desired "silvery" or bright metallic lustre, but be of a dark cast and still be good, if it is only large and of a hard character, possessing good structure in cells.

Black ends afford an example of the above and there is considerable difference of opinion as to their evil effects. In an able paper on coke by Mr. C. K. Pittman, read before the Western Foundrymen's Association in January, 1894, a case is cited of "black ends" giving the best analysis. In a discussion of Mr. Pitt-

man's paper, one member referred to two heats being melted under as nearly similar conditions as was practical, one with the cleanest sorted coke and the other with the "dark ends" from the same car. The latter gave twice the depth of chill which the clean coke gave. I would not be guided by such a chill test unless accompanied with a fluidity test, for the simple reason that difference in the fluidity of the iron might cause the difference in depth of chill, and all experienced founders know that with the same coke and conditions practically the same, as far as it is possible to have them, the fluidity in two heats can differ, and again, there might have been more delay in pouring one chill test than the other. As far as my experience goes, I cannot say that I can especially refer to any time when "black ends" gave me trouble, although I always prefer the bright, silvery-looking coke.

Table 4 is an average of several analyses of Hecla coke from the Connellsville region. The writer has used this coke extensively at his foundry:

TABLE 4.

Moisture	.058
Volatile matter	.634
Fixed carbon	89.960
Sulphur	.790
Phosphorus	.014
Ash	8 554

"Forty-eight-hour coke" and "72-hour coke" refer to the time the coal is subjected to the process of coking in the oven. Seventy-two-hour coke is generally due to Sunday coming in as an odd day and one upon which the cokers are taking their rest. The preference of founders for 72-hour coke is not always accompanied by the assurance that it has the high quality

that many claim for it. I have melted with all furnace, or 48-hour coke, for six months at a stretch, and I cannot say that the simple fact of its being a 48-hour coke caused it to be unsatisfactory. Nevertheless, there are conditions about 48-hour coke which are very apt to make it of less value as a good melter than 72-hour coke. These arise from the fact that 72-hour coke is generally selected with greater care, with the probability of containing less sulphur than 48-hour coke. As solid a coke may be produced from a 48-hour as from a 72-hour burning; but owing to the conditions permitting a furnace to use a smaller and more dusty coke with less evil results than are apt to follow in cupola work, 48-hour coke is not selected or handled with the same care as 72-hour coke, and hence the former will give a greater yield from the coal used. This permits it being sold at a lower price. If the same care were taken in burning and selecting the 48-hour coke as with the 72-hour product, as can be done if so desired, the chances are that the former could generally give good satisfaction in cupola melting. There are times when coal is only coked 24 hours in beehive ovens, but this product is not considered at all suited for melting or smelting purposes, although coke makers have been known, it is said, to ship 24-hour coke for the 48-hour article.

The process of washing coal is this: The bituminous coal used for coking may be in lump or slack form. It is often found containing iron pyrites or sulphur and slate to such a degree as to require that it be "washed." This consists in crushing the coal, if it is of lump form, so as to make it fine like slack, and then carrying it by means of buckets attached to an endless chain

from boat, car or crushers to tubs of water so arranged with "jiggers" that a constant agitation and flow of the water causes the different elements in the coal to take their place in the water according to their several specific gravities. The sulphur and slate, being heaviest, sink to the bottom, and by a series of jigging tubs, through which the coal is passed, the floating bodies — the coal, partially freed of its sulphur and slate — are caught by perforated iron buckets, on an endless chain, and carried to a dump pile or to the "larries," an iron rigging used for carrying the coal to the ovens to be charged for coking. The impurities, in the form of slate and iron pyrites which have sunk to the bottom, are passed along through the shutes with the outflowing water to the refuse bed. The washing process often removes bitumen with the slate to such a degree as to rob the coal greatly of its coking qualities.

In conveying the coal to the oven, enough is generally carried by one larrie, A, to fill an oven at one charge. This larrie runs on a track over the top of the oven, as shown at B, Fig. 1 (which, with the other illustration, from drawings by Wilkins & Davison, of Pittsburg, is taken from Part III, of the Annual Report of the Secretary of Internal Affairs, State of Pennsylvania, for 1893). By a handy dumping arrangement the coal may be delivered into the ovens on either side of the track. After the coal has been dumped into the ovens through the hole E it is leveled by means of a long-handled hook. This done, the door D is then partially closed by means of bricks loosely laid or luted with clay or loam, an opening of about six inches being left at the top of the door for the admittance of air to sup-

port combustion in the oven. As the coking progresses, the opening for the admittance of air is occasionally made less and eventually closed, in connection with the charging opening E.

Combustion of the coal results from the heat which the oven contains from the previous coking. As soon as the coal is ignited, which is about an hour after it is charged, a black smoke, combined with a greenish vapor and occasional outbursts of flame, passes up through the charging hole E, which is left open to create draft and permit the escape of all smoke and vapors that may emanate from the coal. The gas which escapes has an odor, sometimes strong of sulphur. The smoke generally ceases in from 10 to 12 hours after the first ignition of the coal, after which a bright flame passes through the opening E and covers the entire surface of the coal, which by this time has attained almost a white heat. This process continues until the bright flame dies out and then the coal simply becomes one mass of red-hot coals containing about one-third of the volatile matter originally in the coal, two-thirds having passed off during the time the body of the coal was raised to its highest temperature. As soon as the 48-hour or 72-hour coking period, as the case may be, has matured, or the oven is "around," a stream of water from a one-inch hose (or the water may be thrown by buckets) is sent in over the top surface of the glowing mass to extinguish the fire. It is very important to cool off or stop all further combustion at this point of the coking, as, if permitted to continue burning, the fixed carbon of the coal would be rapidly consumed, thus causing a material loss of combustible.

The main principle in coking, being the admission of the air to support combustion at or over the surface instead of causing it to pass up through the coal, as in burning fuel for firing boilers, etc., prevents destruction of the coal while coking and causes it to "cake" or become the coke of industrial commerce. Thus, instead of the fire burning from the bottom upward, it burns downward, creating an action of distillation more than one of combustion. Some of the carbon in the coal is lost in the process of coking, as previously stated. If cooled off with water at the proper time, the percentage of carbon lost during coking rarely exceeds 20 per cent. and may not go over 10 per cent. The amount of the loss is due to many factors. One may be the indisposition of the coal to coke, and again there may be causes local with the ovens and their treatment. Some have followed the practice of drawing the coke from the ovens before cooling it off with water. The method of cooling the coke on the inside of the oven is hard on the bricks composing the interior, but it makes easier and more comfortable work for the cokers and is generally considered to be the better method of the two, in so far as it relates to the question of moisture in coke, as it is claimed the product absorbs less water by being cooled off inside than outside of an oven.

The amount of coal charged into such a beehive oven as described herewith covers the floor to a depth of about two feet for 48-hour coke and 2½ feet for 72-hour coke and in weight ranges, according to the diameter of the oven, from about 3½ to 6½ tons.

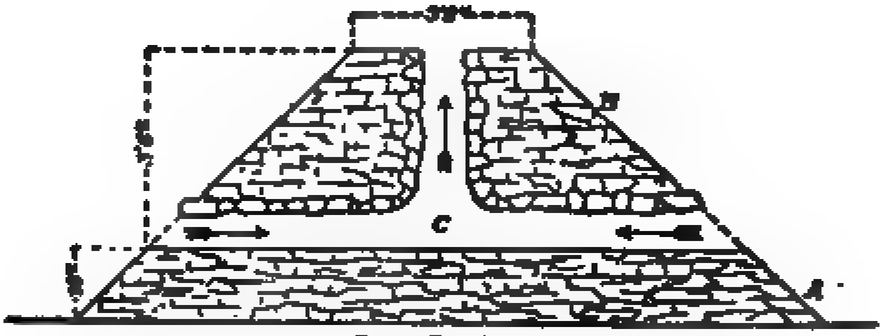
Water in coke can range from 15 to 20 per cent. of its weight. As it takes about 15 pounds of coke in a cu-

pola to evaporate one pound of water, it is evident that the less water coke contains the more economy in melting or the less fuel required. Some firms recognize this factor and build stock houses for keeping the coke under cover. It should be remembered that coke which has been subjected to rain, mist or snow requires a greater percentage to obtain the same fluidity than if it has been a dry coke. It is claimed that exposing coke or iron ore to rain and sunshine, or out-door weather, will reduce its sulphur. To what extent this is true, the writer is unable at present to state.

Before drawing the coke, the glowing mass is cooled off with water, as above noted. The coal as it lies "caked" or "coked" in one solid mass is full of vertical seams or cracks caused by the contraction or cooling of the glowing mass. These seams put one in mind of a partially quartered piece of fruit, only awaiting the insertion of a little force to finish its separation. The cokers insert their hooks between these seams in drawing the coke from the oven. It is landed on the coke wharves H, from which it is loaded into cars standing on the track R, and shipped broadcast to consumers. The care exercised and the time taken in drawing the coke from the oven have much to do with its size, freedom from "braize" or small coke, and the yield of coke. The method adopted for obtaining "selected coke" lies in picking out the "black ends" and fine as well as soft or poorly burned coke. As soon as coke has been withdrawn, the oven is again filled with a charge of coal, the drawing door closed and the heat of the oven from the previous coking, as stated before, ignites the fresh coal and "another heat is on," as the founder would say.

The method generally used for coking in the United States is that found in the beehive oven as illustrated in Fig. 1, page 5. These ovens are generally built from 10½ to 12 feet in diameter and from five to seven feet in height. The outside circle is placed within that of two as shown in the plan view, for the purpose of admitting general uniformity of expansion and heat among the ovens. The interior of the oven is all fire-brick and the space between the ovens is packed with clay or loam. Pillars, as at K, are used for the support of the larries on the track B so as to take their weight off the arch of the ovens. The outsides of the ovens at S are built of stone and are made very strong. The filling is all clay or loam, and the floor X is composed of tile fire-brick. Most of the details here given are those which the author took note of while inspecting the methods, etc., of coking, as described heretofore.

Coal is sometimes coked in mounds, heaps or piles, similar to the method used for making charcoal from wood. It was by such methods that coke was first made. By such methods of coking, the coal must be chiefly in lumps and piled in a manner to leave all the air space that is practicable through the body of the mounds, etc., and also have it piled so as to have as little of it touch the ground as possible. The mounds or piles are generally built around a brick chimney laid with loose bricks, left as full of holes in every other course in height as is practicable so as to provide openings for draft from the outside of the mound at various heights. These piles range from 15 to 30 feet in diameter and from four to seven feet in height. They are set on fire by means of openings



Cross Section.

Ground Plan.

FIG. 2.—COKING IN MOUNDS.

left in their body where wood or light brush can be inserted. Some piles are built in an oblong form, often running 200 feet or more in length, with a base in width of from 12 to 16 feet. The plan of building such long piles, is to lay a body of coal about 16 inches high and then commence the formation of flues as seen at C, Fig. 2, page 19.

These flues are filled with wood, brush, or any light kindling, and then set on fire at every other opening, the aim being that no one part of the pile burn faster than another. If a fire should be too strong at any one point, the outside surface is banked with fine coke dust or earth, and applied to the surface of the whole structure as soon as the gaseous matter has stopped burning, so as to smother the fire and complete the coking of the coal. The last operation with this method of coking is to pour a little water down the vertical flues, so as to diffuse steam throughout the whole body of the coke, which, it is claimed, is beneficial, resulting in the least moisture in the coke. It takes from five to eight days, according to the state of the weather, to perfect coking by this plan. The coke produced by it is said to be of very good quality; but, as a general thing, there is considerable loss in the yield where coal is coked in mounds or heaps, and the method has the disadvantage of requiring the coal to be in lumps.

The yield of coke obtained from heaps or mounds generally ranges from 50 to 55 per cent. of the coal charged, whereas with oven coke the yield is from 60 to 70 per cent. The long mounds are said to be productive of better coke and furnish a larger yield than round or small oblong piles, having simply one center

draft provision as heretofore described. It is only where it is costly to secure building material and coal is cheaply obtained, or where the coking qualities of coal are desired to be tested before expensive ovens are erected, that mounds are generally used to coke coal. The following table showing the yield of a few different grades of Connellsville coke, prepared by Mr. John Fulton, and published in the *American Manufacturer* of February 10, 1893, will prove of interest:

TABLE 5.—YIELD OF COKE FROM COAL.

No. of test.	Time in oven.	Coal charged.	Ash made.	Fine coke made.	Market coke made.	Total coke made.	Per cent. of yield.				Per cent. lost
							Ash.	Fine coke.	Market coke.	Total coke.	
	h. m.	lb.	lb.	lb.	lb.	lb.					
1	67 00	12,420	99	385	7,518	7,903	00.80	3.10	60.53	63.63	35.57
2	68 00	11,090	90	359	6,580	6,939	00.81	3.24	59.33	62.57	36.62
3	45 00	9,120	77	272	5,418	5,690	00.84	2.98	59.41	62.39	36.77
4	45 00	9,020	74	349	5,334	5,683	00.82	3.87	59.13	63.00	36.18
		41,650	340	1,365	24,850	26,215	00.82	3.28	59.66	62.94	36.24

This Table shows that 48-hour and 72-hour coke vary more or less in the length of time such designated coke is actually in an oven and that the actual time coal is coked is largely regulated by local conditions favorable to suit the best working convenience of the cokers in going their rounds of the ovens, and in one sense, we might say, instead of 48-hour and 72-hour coke, two-day and three-day coke. It also clearly illustrates the loss of coal in the form of what is generally called "braize," or small, fine coke, and that of the ash produced by the burning of coal.

It is claimed that where machinery is used instead of mules and hand labor for charging ovens, the coal

is generally insured a longer coking than 48 or 72 hours, the reason given being that by the use of machinery the ovens can be charged earlier in the day than is practicable with mules and hand labor.

It was at one time generally thought that Connellsville coke could not be equalled, and that any other variety was unsuited for cupola or smelting work. But of late years experience with other cokes has shown such opinions to be in error, and to-day localities shown in Table 6, by Mr. John R. Proctor, given in the Kentucky Geological Survey Report, are furnishing large quantities of good coke to founders and furnacemen. The Table also presents a chemical analysis of the various brands of coke mentioned.

TABLE 6.—ANALYSIS OF COKE.

Where Made.	Fixed carbon.	Ash.	Sulphur.
Connellsville, Pa. (Average of 3 samples.)	88.96	9.74	0.810
Chattanooga, Tenn. " " 4 "	80.61	16.34	1.595
Birmingham, Ala. " " 4 "	87.29	10.54	1.195
Pocahontas, Va. " " 3 "	92.53	5.74	0.597
New River, W. Va. " " 8 "	92.38	7.21	0.562
Big Stone Gap, Ky. " " 7 "	93.23	5.69	0.749

Chemical analysis of any certain brand is, as a general thing, not an evidence that all coke coming from such ovens will always be up to the test reported, for there are many chances of conditions changing so as to create different chemical and physical properties in coke from the same ovens. The safest guide is the general reputation of a coke and personal experience in using any special brand. This is not saying a chemical analysis of coke is not valuable. A chemical analysis of any shipment will only approximate the constitu-

ents of such coke. There are cases where it will pay a founder to assure himself fully as to the chemical properties of coke in his yard before he uses it. In sampling coke for analysis, much more should be selected than is actually required, and what is selected should be carefully picked from different parts of the pile, owing to conditions often causing a variation in the chemical qualities of coke from the same oven and the chance of the product of two or more ovens being mixed in the same car.

Whatever brand or quality of coke a founder may use, he cannot be too exacting in striving to obtain at least a fair article. A poor coke for melting purposes, at any price, is an investment sure to lead to loss in the end.

Coke in its natural state is found, though few are aware of the fact. Appleton's Encyclopedia cites a bed existing on both sides of the James River and near Richmond, Va. It is said to be hard, very uniform, dark in color but rather porous. It is claimed to be serviceable for melting purposes.

By-product coke ovens for local utilization. Commencing with 1896, a combine among Connellsville mine owners raised the price of coke to such a point that it has inaugurated a movement among independent firms owning steel plants and blast furnaces to erect at their works by-product coke ovens, whereby they can have coal shipped to them and make their own coke. By this process, in connection with the by-products, such as gas, sulphate of ammonia, tar and other elements produced, it is claimed they can make a very good percentage of profit on the money invested in the erection of the coke plant and also be wholly

independent of the coke manufacturers. It is said that out of a ton of coal come 10,000 feet of gas, and out of 1,500 pounds of coke come 25 pounds of sulphate of ammonia, and 90 to 100 pounds of tar, with certain cyanides and other by-products.

The gas from such ovens would prove of much value for many foundries in drying moulds, cores, etc., and running boilers. A blast furnace not far from our foundry is at present using a plant of 24 by-product ovens of the Semet & Solvay design, which works well and requires but 25 to 30 hours to coke the coal, and from all reports, it is not going to be long before many other blast furnaces will possess ovens of similar character. It will pay founders to keep an eye on this movement, as many large foundries, or a combination of small ones, may be able to not only make their own coke but, in many instances, obtain all the gas they can use, and by the sale of the by-products cause such ovens to be a paying industry.

It is said that by-product ovens of the above design can produce cheaper coke than Connellsville from an inferior grade of coal and produce gas for eight cents per 1,000 feet. As this gas can be piped for miles, there is no telling what benefit the founder may not derive in the future from this new departure in the manufacture of coke.

Generating electricity from coke. Taking the advance recently made by William W. Jacques, an electrician of the Bell Telephone Co., in directly converting coal or coke into electricity, we are certainly led to recognize the coke industry as being of no small importance. Dr. Jacques, it is claimed, has devised a process of singular simplicity to generate an elec-

tric current direct from coal or coke, and it is said in a series of tests has been able to secure in one instance as high as 87 per cent. of a theoretical efficiency of the coal used. It is also asserted that he believes he will be able to produce electricity commercially for about one-fifth to one-tenth its present cost. His method is patented and simply consists in taking a quantity of coke and reducing it to a powder, to which is added a little water, after which it is pressed into an iron cylinder mould to make a round stick of carbon that looks like an electric arc light carbon, only of a much larger size. This stick of carbon he suspends in a cylindrical iron casting containing an electrolyte of melted caustic soda. When a current of air, introduced by a small tube, is driven through this solution, electric action is set up, producing a current of extraordinary volume. If Dr. Jacques' expectations are realized, his invention will play no small part in furnishing motive power to makers and users of iron.

CHAPTER II.

ELEMENTS IN IRON ORE, METEORITES AND MILL CINDER IRON.

A knowledge of the raw materials from which cast-iron or pig metal is derived can often be of value to the founder and users of castings. It is said the Greeks claim that the discovery of iron was caused through the burning of a forest on the mountain of Ida, in Crete, in 1500 B. C. The heat of the fire and charred wood lying on the ground could have caused the surface of the earth during the conflagration to have been raised in temperature to a state of fusion. If there was iron in the soil or rock forming the surface of the ground, it would naturally melt and run in a fluid state into the depressions or holes in the ground, to be there discovered as small bodies of iron. It is reasonable to believe that the manner described would be the most apt to direct attention first to the fact that soil and rock of the earth contain iron. When we look at the raw material from which iron is obtained, it seems difficult to realize that the different forms of castings, which we have the present day, originated from such crude and apparently worthless material. Not until we watch the dirt and stone, as we might call them, being charged into the top of a blast furnace and being tapped out at its bottom as a bright,

seething mass of beautiful liquid metal, are we awakened to comprehend the full value of the dirt or rock called "iron ore." The presence of iron in earthy matter is said to be due to the materials contained in the ground being acted upon by the carbonic acid and oxygen of the air, which cause decomposition of vegetable and organic matter. Iron ore is thus chiefly an oxide of iron, containing more or less impurities according to the percentage of iron in the ore, and called "rich ore" when high in iron and "lean ore" when low.

The chemical composition of iron ores is generally oxide of iron, silica, sulphur, phosphorus, lime, magnesia, alumina and manganese. We may also find carbonic acid, titanic acid, phosphoric acid, sulphuric acid, potash, copper and organic matter, only traces of which may appear. The oxides of iron are known as "ferric oxide" and "ferrous oxide." The former contains 70 per cent. of iron and 30 per cent. of oxygen, the latter 77.78 per cent. of iron, 22.22 per cent. of oxygen. Percentages of iron and oxygen will vary in these oxides, but the above combinations are generally recognized as constituting distinct proportions in defining their composition.

Some, in defining the percentage of iron in ore, call it metallic iron, and then again others simply speak of it as iron, when referring to the chemical properties of iron ore. Almost all kinds of sands, clays and rocks contain more or less oxide of iron, but such material is not generally considered an iron ore unless it has over 30 per cent. of iron in it. Ores are now very rarely used for making iron or pig metal unless they contain over 40 per cent. of iron. The ore

used in the manufacture of pig metal that can be worked to an economical advantage, generally contains from 50 per cent. to 65 per cent. of iron. It is rarely the case that ore of sufficient quality to keep a furnace going steadily on a fair uniform product can be obtained having over 70 per cent. in iron. Ore has been found on the north shore of St. Joseph's Island, Lake Huron, Ontario, having 97 per cent. of iron in it. An account of this was given by Mr. G. C. Hoffman in the "Transactions of the Royal Society of Canada," Vol. 8, 1890. This is by many called a "native iron" instead of an iron ore, and might be said to approach what is obtainable in meteorites which have fallen to the earth from the heavens, bodies which are often of great size and weight.

The meteorite found at Santa Catatina, in Brazil,* weighs twenty-six tons, and the San Gregorio meteorite, seen in Fig. 3, is an extremely interesting object.

The following analyses, Table 8, of meteorites taken from different parts of the world, show their chief constituents to be metallic iron alloyed with nickel:

TABLE 8.

Locality.	Iron Per cent.	Nickel Per cent.	Analyst.
Siberia	96.75	3.25	Proust.
America	97.5	2.5	Proust.
Hungary	96.5	3.5	Proust.
Bohemia	98.5	1.5	Proust.
Eastern Cordeilleras	91.41	8.59	Boussmgault.
Louisiana	90.02	9.67	Shappard.

Iron Meteorites might be called iron ore of other worlds, often seen coming to us as shooting stars.

* Iron Age, June 6, 1895.

FIG. 3.—SAN GREGORIA METEORITE.

They present the main evidence we have of our world being similar to other planets in possessing metals. We dwell on this point, and first note what Dr. Ludwig Beck says of meteorites in "The History of Iron," translated by the *Iron Age* in its issue of March 28, 1895:

"To fix a definite time or period for the discovery of iron would be a useless undertaking. Iron is found with the oldest historical people. It is a common belief that the first iron used by man was meteoric iron. Meteoric iron has been found at all points of the globe. Considerable masses of it were found in the Magura Mountains in Hungary, near Kabija, in South America, near Tuluca in Mexico, on the Fish River in Africa, at Diska, Greenland, and other places. A mass of meteoric iron near Krasnajarsk, in Russia, weighed 1,800 pounds; one on the Red River, in Louisiana, 3,200 pounds. A mass of 19,000 pounds was found on the River Bendego in Brazil, and one, estimated to weigh 33,000 pounds, was found at Otumba, Peru. In the thirteenth century B. C., the falling of meteors is chronicled. Plutarch and Pliny mention such occurrences. Meteors were often used as sacred sacrificial stones in Asiatic countries. Such a sacred stone is the meteorite Hadscharel Aswad in the Kaaba at Mekka. It is mounted in silver and is said to have fallen from heaven as a ruby, but the sins of mankind turned it black. This is the oldest known meteorite.

"Meteoric iron is chemically and physically radically different from our artificial iron. The meteoric iron is rarely a homogeneous mass. It is composed of different substances. Remarkable is the transition from meteoric stone to meteoric iron. Most meteoric stones carry more or less meteoric iron. In a more advanced stage of transition a skeleton of iron was found. In the last or more perfect cases the stony nature of the meteorite disappears, and it becomes a mass of iron characterized by a peculiar structure never found in any similar form in artificial iron. Meteoric iron being essentially different in its chemical composition and physical qualities, its malleableness varies considerably. Of 70 meteorites, 48 proved to be malleable and 7 were absolutely unmalleable. American scientists have found the meteoric iron

discovered in this country as very malleable. Dana says: 'Meteoric iron is perfectly malleable and may be readily worked into cutting instruments and put to the same uses as manufactured iron.'"

The pig iron which the founder uses (barring ferro silicon, etc.) generally contains from 92 to 96 per cent. of pure or metallic iron, with four to eight per cent. of impurities, chiefly in the form of sulphur, phosphorus, manganese, carbon and silicon. These impurities, while being called such, are really the elements which make our iron of any practical value in the various industries. According to the slight changes in the proportion of these so-called impurities are we given the different "grades" of pig metal so essential to meet the varying conditions called for in our widely diverse uses of iron at the present day. A metallic or pure iron, so called, would be of little or no value to us.

Silica is a quality in iron ore generally possessing percentage nearest to the iron, which the ore also contains. This ranges all the way from a trace up to twenty per cent. and often over, but that generally used contains from three to eight per cent. of silica. The greater part of it is carried off in the cinder or slag. Many claim that little goes to make silicon in the iron, and that most of the silicon in the iron is obtained from the fuel. The higher the temperature in the fusing zones, the greater silicon will be found in the iron and the less the silica in the slag.

Alumina is a mineral contained in iron ore, ranging from a trace to ten per cent., and, in what are called aluminous-ores, from ten up to thirty per cent. It is mostly carried off by the slag, and where iron ore is high in alumina it is very injurious to good work, as it

prevents a furnace from "driving well," owing to its being very refractory to flux or melt. When there is an excess of alumina in ore it is generally found necessary to mix higher silicious ores and more limestone with it, in order to make it flux properly and run with sufficient freedom as slag or cinder from a furnace. Alumina is the only known oxide of aluminum. When pure, aluminum is a white, light metal, possessing a specific gravity of 2.6 to 2.7, and is the lightest of all useful metals except magnesium. Its ores occur in all clays, and form the greater part of the earth's crust. Alumina is a very difficult oxide to melt; only the highest temperature affects it.

Limestone is a grade of rock composed largely of carbonate of lime in which lime may exist from 10 up to 56 per cent. Dolomite, chalk and marble are species of limestone. In the form of dolomite, it is a mixture of the carbonates of lime and magnesia containing, when pure, 54 per cent. of carbonate of lime, 45.7 per cent. of carbonate of magnesia. A great deal of white marble is dolomite, crystallized under very heavy pressure. Marble chips, as well as dolomite or lime, therefore, make a good flux for a furnace or cupola, but the former, on account of its scarcity, is practical only for cupola work. Marble differs from limestone in being more clean, solid, and of a more clearly defined pure color. It is said that limestone emanated from shells and corals which had been crushed together by the actions of the waves. Limestone generally contains more or less impurities in the form of sand, clay and talc. The greater the percentage of carbonate of lime limestone contains, the better it is as a flux for blast furnace or cupola work. Lime is found so

high in iron ore in some sections as to make the ore self-fluxing, but as a general thing the ore used or readily obtainable ranges from a trace up to ten per cent. of lime as commonly used. For analyses of limestone, see Chapters VII. and XLVI.

Manganese is found in nearly all iron ores to a greater or less degree. It readily alloys with iron and, if conditions are at all favorable, manganese will generally be found very uniform in the pig metal daily produced. All the manganese contained in pig metal is obtained from the ore. When ores are high in manganese the slags are generally either green or brown. Much manganese is carried off with the slag, and it will carry sulphur with it, owing to the great affinity which manganese has for sulphur, and for this reason it is a property often very desirable to be contained in mixtures, to aid the process of smelting.

Manganese occurs in ores in the form of a manganese dioxide and manganese oxide. Some ores are so high in these properties that they are called "manganiferous ores," and of late years their reduction has been achieved in a blast furnace as readily as iron ore is reduced, although at one time it was thought impossible to obtain metallic manganese from the blast furnace.

Ferro-manganese is obtained by smelting manganiferous ores in a blast furnace and is placed on the market as a commercial product containing from 20 per cent. to 90 per cent. of manganese.

Spiegeleisen is a product of manganiferous ores, but lower in manganese than ferro-manganese. It ranges from 7 per cent. to 20 per cent. in metallic manganese. In this form it generally presents a silvery white fracture with a crystalline structure. By some, this metal

is called "looking-glass iron" (the English rendering of *spiegeleisen*). Spiegeleisen is readily produced whenever sufficient manganese is present in the ore. Both these metallic manganese metals are chiefly used in the manufacture of steel in its many and various grades.

Manganese in ore is frequently referred to as metallic manganese, just as is the iron which iron ore may contain. When manganiferous ores are smelted in a blast furnace, metallic manganese is obtained. It exists in other forms than that of a metallic character, and is greatly used in the manufacture of chlorine and bleaching powder, and also in the manufacture of glass. Manganese can make iron so hard that glass can be scratched with it, and it is now being widely used in alloy with iron and steel to manufacture armor, shot-and-shell, etc. It has proved a remarkable metal when combined with iron and steel to resist penetration or destruction from the highest power derived by the use of explosives or powder. In the year 1839, Mr. J. M. Heath took out a patent on alloying manganese with steel. Much credit for the present achievements in this alloy is due to Mr. R. A. Hadfield, of Sheffield, England, who has made such advances in this line that the manufacture of manganese steel castings is at the present day a recognized industry of considerable importance and of great value to the metallurgical world. Manganese is found in all the States bordering on the Atlantic Coast, the Great Lakes and the Mississippi River, as well as in other States, including Pennsylvania, Virginia and Vermont. It is found in England, Spain, and other parts of the world, in manganiferous ores, as well as in other ores.

Phosphorus exists in most iron ores as a non-me-

tallic element. It is also found in shells, bones and fish, as well as in the rock or soil of the earth. It is a very light substance, and as manufactured for commercial purposes it is produced in small round sticks, which must be kept in water until wanted for use. Some brass founders submerge sticks of phosphorus in melted brass so as to make their metal higher in phosphorus for the purpose of making it better able to resist friction. It is readily absorbed by iron or brass. The old school of chemists used to call it the "Son of Satan," because it glows in the dark. Phosphorus is also largely obtained from the bones of animals by a distillation with carbon condensed in water. About all the phosphorus contained in the ore, fuel and flux is absorbed by the metallic iron when smelting, owing to the great activity of iron in absorbing and retaining phosphorus, combined with the inability of lime or slag to carry it off. Unless the phosphorus exceeds three per cent. in the iron, a basic slag may be formed to carry it off slightly. With the exception of iron for basic steel purposes, and very high phosphorus foundry irons, the furnaceman is generally very careful against obtaining high phosphorous ores, and no doubt more time and money have been expended in experiments to originate devices to remove phosphorus from iron ore than any other element which it contains. Improvements have advanced in the line of removing phosphorus to such a degree that the difficulty is chiefly now confined to non-magnetic ores.

Phosphorus can be largely if not wholly removed from magnetic iron ore by means of permanent or electro-magnets. In "Notes on Iron and Iron Ores," by Dr. T. S. Hunt, printed in the transactions of the

American Institute of Mining Engineers, 1890-91, the writer says:

"A process of partial reduction at a low red heat will render non-magnetic iron ores attractable by the magnet, a reaction of which Chenot long since proposed to take advantage, for the purification of such iron ores as are not naturally magnetic."

Just how practical the above plan is, the author has not learned, but it is evident that at the present low price at which iron ores can be purchased to manufacture all the various qualities of pig metal required, there is very little encouragement for the employment of any device which would materially increase the cost of iron ore in eliminating its phosphorus from non-magnetic ores.

Where magnetic iron ores are treated to lower their phosphorus they are generally first heated or partially roasted so as to make them friable to facilitate crushing; then they are passed through a crushing machine and screened to size, after which they are carried by machinery to permanent or electric magnets so arranged that, when the iron ore falls on them the parts containing iron will adhere to the magnet and the part composed of earthy matter or refuse not possessing any iron will fall off the magnet into a pile by itself, while the iron element of the ore will be collected in a separate pile. The matter not attracted by the magnet is called "tailings," and that which adheres to the magnet is called "concentrates." It is seldom, if ever, that the magnet can attract all the iron in the iron ore which passes over it. From five to ten per cent. of the iron in the ore is generally lost in the "tailings," which in some cases are utilized as low-grade ore, or mixed in small percentages with high-grade ores in

order to save what little iron may have been conveyed in the refuse. There are many different kinds of devices patented for the purpose of dephosphorizing magnetic ores. The accompanying illustration, Fig. 3A, will convey an idea of the principles involved in the separation of "tailings" and "concentrates" by the employment of magnetic power.

Magnetic ores high in phosphorus can often be rendered suitable for making Bessemer pig iron by the use of a "separator." Edison has succeeded in obtaining concentrates suitable for making Bessemer iron from an ore possessing 1 per cent. of phosphorus. By the use of separators or magnets, from 75 per cent. to 90 per cent. of the phosphorus originally contained in ore is said to be removed. Sulphur, where it exists as pyrites (which is a combination of three parts of sulphur with two parts of iron), in magnetic ores can have, it is also said, a larger percentage of its sulphur removed by magnetic concentration or a separator than by roasting. Sometimes the sulphur exists more as pyrrhotites (which is eight parts of sulphur combined with seven parts of iron), in which state ex-

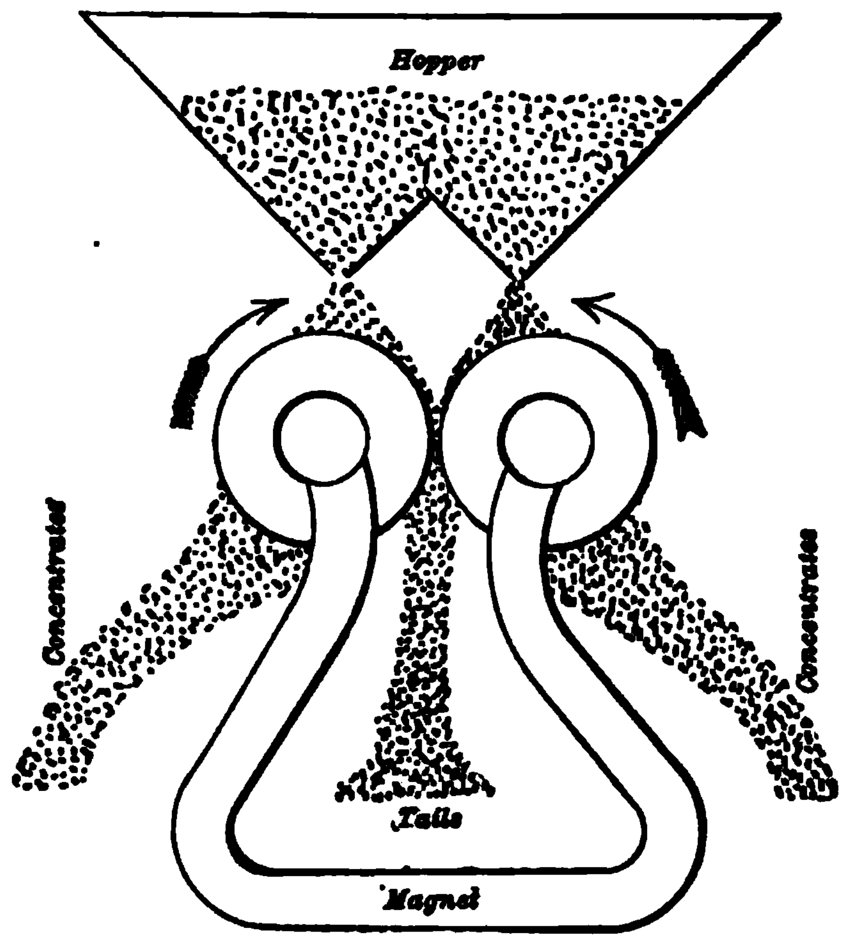


FIG. 3A.—BUCHANAN SEPARATOR.

periments have shown that there would be more sulphur in the concentrates than existed in the crude ore, and hence separators with this class of ore to eliminate sulphur have proved a failure.

Magnetic ores are chiefly a hard material, which must be crushed or broken to size to suit the varying conditions of smelting. In Canada and New Zealand, magnetic ores exist in the form of a coarse gravel or sand, making fine-grained ore, which, as a rule, furnacemen prefer not to use if it can be avoided, for reasons explained in Chapter VI. Magnetic ores are often discovered by their polar attraction for the compass needle. It is said that when the authorities first surveyed the State of New Jersey, great expense was incurred and work had to be gone over again owing to the influence the magnetic ore had in driving the point of the compass from its true course and the surveyor's lack of knowledge of the properties of magnetic soil and rock. Magnetic ores are found in most parts of America and throughout the world, and are often very free of phosphorus and sulphur, but if they are too high in phosphorus and sulphur, they will not be used as long as sufficient ore of suitable grade can be obtained without the cost necessary to prepare high sulphur and phosphorus ore for smelting.

Low phosphorus ores are generally of much more value than high phosphorus ores, especially for Bessemer pig iron, in which phosphorus must not exist above .10. In foundry iron, phosphorus is desired to be higher than in Bessemer, and it is often found beneficial to have pig metal contain as high as 1.5, owing to the fact that phosphorus possesses the quality of giving "life" to molten metal.

Sulphur in iron ore is very undesirable and high sulphur ores are often subjected to a process called "roasting," or calcination, which generally drives off a greater part of the sulphur.

Roasting the ore is simply getting the ore to a state of partial combustion; the same as coke might be heated in a fire-place to incandescence and then allowed to die out. The ore being heated to a temperature ranging from 1,000 degrees to 1,500 degrees F., and arranged so that the air is freely admitted, becomes very porous, thus enabling the oxygen of the air to penetrate the body of the ore, thereby permitting volatilization of sulphur and causing the ore to become more highly oxydized and consequently better prepared for reduction in the blast furnace. There are many different methods employed for roasting and calcining ores, some of which are covered by patents.

Ores are sometimes roasted by simply piling alternate charges of ore with sticks of wood or brush in the open air and allowing combustion to go on until the fire dies out of its own accord. Again, it may be enclosed in layers within a brick structure and fired after the manner just described. A plan which provides a convenient method for roasting ore is that of charging the ore in layers with small coal in what is generally called a "shaft," something after the plan of a straight cupola, differing mainly in principle, so that the material may be taken out at intervals of time by continuous descent by means of "shutes" arranged around the sides of the bottom of the shaft, to be alternately opened and closed so as to permit any degree of speed required in roasting.

Varieties of iron ore are almost without number. In

order to classify them, they are chiefly placed under one or the other of the following heads: Hematites, Magnetites and Carbonates. Of the first, there are two qualities, known as the red and the brown hematites. There is more red hematite used than all the other ores combined. Red hematite is also largely used for making paint mixtures, one of which is the well-known "iron ore paint."

Red hematite is generally the most free from sulphur and phosphorus, although there are a few species cited in Spain where this ore runs very high in phosphorus. Red hematite is found both in soft and hard ore and is called red because of its having or making such a color when rubbed against other material. It is found in veins and large, deep deposits, and in fact in almost every shape in which ore is found. It exists in large quantities and is found on the shores of Lake Superior, in Georgia, Missouri, Ohio, Tennessee, Alabama, Norway, Ireland, England, Germany and Spain. Mesabi ore, a soft ore, now largely used to make both Bessemer and foundry iron, is a hematite, which was thought a few years ago by experts to be impossible of reduction in a blast furnace on account of its being such a dusty, fine material.

Magnetic ore is the next generally recognized in order of classification. This ore is chiefly found in veins and is generally classified with the refractory ores. It is generally a dense, black material, often highly polar or magnetic, as referred to in the preceding part of this chapter. The massive magnetic ores are chiefly found in England, North Wales, Norway, Lapland, Sweden, Spain, Russia, France, Germany, Africa, Portugal, Greece, Italy, Brazil, Australia, New Zealand

and India. In America, they are chiefly found in New Jersey, New York and portions of the Lake Superior country.

Brown hematites include bog ores, which are found in shallow rivers, etc., and are now little if any used, and largely result from the oxidation of the carbonate of iron. No ore is more irregular in its characteristic qualities. It may be of a yellow as well as a brown color; in fact, it is said to be found in many other shapes and qualities. It occurs largely in England, Norway, France, Belgium, Spain, Portugal, Africa, Germany and America. It is generally porous and easy of reduction or smelting in a blast furnace. It is found mixed in undue proportions with earthy and gangue matter and often heavy in carbonate of lime, and also is generally high in phosphorus. It is found in beds and veins and often forms the cover of copper ores.

Carbonate ores are naturally of a whitish color, but they are often found mixed with manganese, which turns them brown. It is largely found in massive veins of great thickness, and by combination with different carbonates, and may be of a greenish gray color. Brown hematites are also found to exist in sands or soil of a coarse character. There is some dispute as to its value; some claim it to often excel red hematites for making high-grade irons. A great variety of carbonate of iron ore is known as clay iron-stone, by reason of its occurring in the clay bands of the coal fields. This class of ore is largely used in Scotland as well as in England. "Black band" is one variety of this class of ore, and is of a glossy black color.

Black band ores are considered the best for giving a

high grade of pig metal, but of late years it has become so scarce as to make it too costly to compete with the most plentiful ores which can be made to produce an iron that will be accepted in most cases as equally satisfactory. An ore approaching black band, and called "band iron" stone, is greatly used. This is of a dark bluish gray color and exists in coal formation similar to black bands, and is found in Alabama, Tennessee, Indiana, Ohio, Pennsylvania, Kentucky, Virginia, France, Belgium, Wales, England and Scotland. Some of these ores are smelted in their raw states, while others are roasted and converted into higher oxides before being smelted.

Moisture in iron ore is a factor of much importance and one which is recognized by furnacemen in making their mixtures. All ores contain more or less moisture or water which, as a general thing, ranges from one to fifteen per cent., often going higher. It is necessary to know the amount of water which an iron ore may average in order to rightly compute the different chemical properties of ores in making a mixture, as it is not long after they are charged into a furnace before the water or moisture is all driven out and the dry ore then commences to assemble its properties to chemically combine with the other elements, to the end of producing the grade of metal desired.

Mill cinder iron is a grade of metal derived from the smelting of rolling mill cinder exclusively, or in admixture with iron ores. Rolling mill cinder can be classed under the heads of puddle, tap cinder, heating furnace, flue cinder, roll cinder and bosh cinder, the latter being collected in a trough or bosh of water in which the puddlers cool their tools. Roll scale is gen-

erally considered to contain the most iron, followed in order by bosh tap and flue cinder.

Tap cinder comprises two forms: one is "boilings" that flow over the floor plate of a puddling furnace when making the iron, and the other "tappings" that run out of a furnace at the end of the heat. As a general thing, "boilings" are very much higher in phosphorus and silica than "tappings." Mill cinder, as above outlined, is composed of protoxide of iron and silica. It contains at times ferric and magnetic oxides and is generally high in phosphorus. Table 9 is an analysis of four samples of mill cinder which the author secured, to afford an idea of the chemical composition of the same. As it would take about two tons of such cinder to make one ton of iron, there would be about twice the phosphorus in the iron produced as is contained in the cinder ore, were all cinder used.

TABLE 9.—ANALYSIS OF MILL CINDER.

	1.	2.	3.	4.
Iron	52.48	52.20	52.91	53.70
Phosphorus	1.32	.34	.47	.37
Silica	24.65	25.06	23.43	23.39
Manganese	.34	.45	.57	.35

It will be seen by the above table that phosphorus is higher than is sometimes desirable in an iron ore. In this quality mill cinder may do harm in pig metal if not intelligently used. Mill cinder is generally only another form of iron ore and is used for two reasons: First, because it can generally be purchased for about one-half what it costs to buy iron ore; second, because it generally contains such a large percentage of iron, often ranging from 40 to 70 per cent. Iron mill

cinder is only used for making foundry or mill iron. It is not used for making Bessemer, for the reason that it would raise the phosphorus too high for pig metal, which for foundry iron is not so objectionable; in fact, foundry iron often requires high phosphorus. It can be said that a few are now using steel cinder in making Bessemer iron, owing to such cinder being very low in phosphorus.

The furnaceman has methods to resort to by which he can partly eliminate the sulphur by fluxing his furnace by means of lime and manganese. It is mainly the phosphorus which is to be feared in mill cinder, as this cannot well be eliminated. If the phosphorus is higher than beneficial in pig metal, there are grounds for rejecting it; but otherwise the founder is not justified in condemning mill-cinder-mixed pig metal simply on the ground that there is actually cinder in the iron. What is required to successfully manipulate cinder-mixed pig is a knowledge of its chemical properties, and not an assumption that the pig metal contains slag because it is made with some mill cinder. Founders have used mill-cinder-mixed pig metal when they thought there had not been an ounce of cinder mixed with the ore. Many would be surprised to know the amount of iron they have used which was a mill-cinder-mixed pig metal. Not only is mill cinder mixed with ores, but furnaces have been kept going steadily making pig metal with simply all mill cinder. The able furnace manager, Mr. C. I. Rader, has done this at the Sheridan furnace, Sheridan, Pa., in making forge or mill iron.

Blast furnace practice has advanced to a very high position of scientific exactness. It is no more a for-

mula of guess work, but the exact chemical properties of all the ores, fluxes and fuel, as well as their chemical affinity for each other, must be known; also the effects temperatures and blast pressures possess to produce the greatest tonnage and obtain the character and grade of iron desired. The furnace managers of to-day must be bright, progressive men, and few can be found who are not constantly striving to obtain all the knowledge they can which is beneficial to their calling.

CHAPTER III.

INTRODUCTION TO FURNACE vs. CUPOLA PRACTICE.

In writing this part of the work it is to be understood that the author is not assuming to instruct practical furnacemen "how to run a furnace." He is mainly illustrating the principles involved in furnace work and how iron is made in a general way, for the benefit of those not thoroughly experienced with such practice, and to also show the founder wherein many of these principles can often be well applied to cupola practice, as he has failed to find any practical writings that serve these ends.*

The first chapter presents knowledge of the principles involved in the design of furnaces and illustrates peculiarities in the construction of the tuyeres and lining. This chapter also gives information valuable in running long heats and saving lining of cupolas. The second chapter will prove of interest in the same line. The chapter on "Charging, Descent and Reduction of Stock" will be found instructive in showing how furnaces are charged, and the causes for diffi-

* In studying furnace methods, the author has been greatly aided by the following gentlemen, who are all experts in various ways in furnace practice, and to whom he here tenders his warmest thanks: Messrs. C. I. Rader, W. A. Barrows, Jr., C. C. Jones, J. J. Pierce, E. A. Wheeler, P. C. Reed, E. M. McAleer and C. B. Kantner, all of Sharon and Sharpsville, Pa.

culties often experienced with such work. The chapter on "Creation of Slag and Flushing a Furnace," combined with "Tapping out and Stopping up," affords a good idea of the general workings of a furnace in delivering molten metal and slag, and how the same are separated by specific gravity to permit the successful drawing of each from a furnace, and will also be of value in advancing cupola practice.

The treatment of moulding and casting pig iron and "open sand work" should be read by every moulder or founder who may be called upon to do "open sand work," as the furnace practice of having "deep floors" and coarse grades of sand has many characteristics to recommend its adoption by the founder. The plans of constructing runners, etc., will also be found of interest. This chapter also treats of sandless pigs.

The question of "direct metal" is one now of importance to many. To be able to take metal direct from a furnace and use the same without remelting it in a cupola means the saving of $1 to $3 per ton, according to the size of the "heats." There are a few lines of work where direct metal can be used, and a study of this chapter will enable all to judge of what might be attempted in this direction.

The chapter on banking a furnace gives a general description of practices followed by furnacemen in "banking," and is of benefit in illustrating methods to prolong a cupola "heat," or carry it over from one day to another without "dropping the bottom."

The balance of the chapters in this part of the work can be studied with profit by all who desire to gain any knowledge of the working and principles involved in "hot blast," or think of adopting the same for cupola practice or any other methods of melting.

CHAPTER IV.

BLAST FURNACE vs. CUPOLA PRACTICE.

CONSTRUCTION OF FURNACES, TUYERES, COOLERS AND SCAFFOLDING.

The author secured the privilege of showing the modern furnace seen at Figs. 4 and 5, pages 50 and 53, through the kindness of the furnace manager, Mr. E. A. Wheeler, of Sharon, Pa. He will use these designs in aiding him to compare furnace with cupola practice, and in beginning would say that improvements in blast furnace practice have resulted in an economy and general advancement far surpassing that achieved by cupola practice.

Furnaces are contracted at the hearth mainly to aid the blast in reaching the center and causing a more even distribution of its pressure throughout the fuel, as well as to save the lining. There are some who advocate building the hearth of a furnace but a foot or two smaller than the largest diameter at the bosh, claiming that it soon burns out if made much smaller; but to judge from my observation and inquiry from many experienced furnacemen, the form of hearth shown is good, as such a hearth can be well maintained through a long service by reason of a good system of water pipes keeping the outside of the hearth cool and lowering the temperature of all the area subjected

to heat. It is also claimed that such a form not only assists the blast to reach the center, but the "batter" or bevel of such a bosh as shown assists in supporting the weight of stock charged, thus lessening pressure at the tap hole, permitting the metal to be under better control, with less liability to cut the breast, as the metal flows out to the runner. When a furnace of the size shown is full of stock (coke, ore and lime), the weight bearing down on the hearth (when a furnace is working properly) is about 100 tons of coke, 160 tons of ore and 35 tons of lime, a total of about 300 tons. Such a weight must be very effective in crushing the almost fusible stock in the reduced body of the bosh, so as to greatly retard the penetration of blast, and is one reason for the high pressure found necessary in furnace practice.

Decreasing the diameter of the stack from its larger portion joining the bosh up to the top, is mainly to assist in preventing the stock from "scaffolding," which in foundry practice means "hanging up." This, as all founders know, is generally due to iron charged forming a wedge to block itself from descending, acting, as it were, like the keystone of an arch, which if once loosened permits the whole structure to fall. "Scaffolding" is due chiefly to a layer of stock being fused to a solid union from the effects of the heat reducing it to a swollen, half molten state on its movement downward to the fusing point, which is said to range from one to four feet above the tuyeres. When furnacemen experience trouble with "scaffolding," etc., not due to a "hot furnace," as described in Chapter XIII., they often resort to the use of more fuel than when all is working well. The additional percentage of fuel

causes a greater heat above the reduction zones, making the stock more plastic, preventing a solid union, and making it give way more easily from the walls of the furnace. It generally takes from ten to fourteen hours for stock to work down from the top to be tapped out as iron.

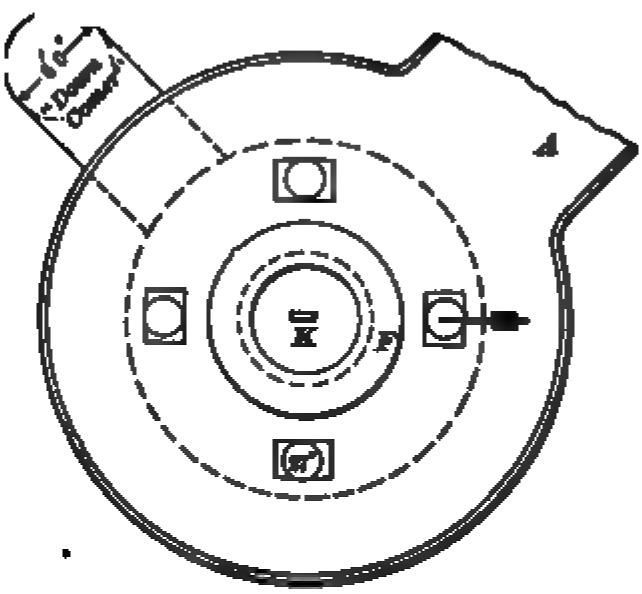


FIG. 4.

The "scaffolding" of a furnace is a very common affair, and one which often results disastrously. I have seen a "slip" cause such an explosion as to lift up the "bell" and "hopper," F and K, throwing them out almost on top of the furnace platform and straining all such parts to such an extent that it was a question whether the furnace shell was safe to be relied upon. I have heard of the bell and hopper being blown about twenty feet from a furnace. Plans have recently been adopted to relieve sudden gas pressure, some of which are working very satisfactorily, especially the system used at the furnace

adjoining our foundry, designed and patented by Mr. P. C. Reed, the furnace superintendent, as shown in Fig. 4. The idea is to build four large openings equally divided around the circumference within a few feet of the top of the stack. These are connected with flues branching upward about eight feet high, and closed by means of valves hung on pivots, as seen at H H, Fig. 4, and so regulated by weight that they will open themselves when any excess of ordinary pressure is created in the furnace. This late improvement is a step forward in furnace practice which greatly diminishes the risks of accidents and loss of life, but it still remains to better guard against the evils of "scaffolding" or the slipping of stock so detrimental to successful furnacing, often requiring several days after a slip to get a furnace back again to working satisfactorily.

A "slip" in a furnace often means the falling of from 25 to 200 tons of stock from a height of 1 to 10 feet. The contemplation of this taking place within a furnace filled with combustible gases, heated stock and liquid metal should enable any one to form some conception of the damage that could be done, and the reason why all hands working around the furnace have good cause to fear a "slip." The "scaffolding" of stock can take place at almost any portion or height of a furnace, and can prove so disastrous as to disable or make unsafe its working parts. In such cases the blast is shut off until necessary repairs are made, and if of an elaborate nature may often call for the "blowing out" of a furnace.

The reason for stock "scaffolding" in a furnace is often found in irregularity in the lining. The constant

friction of the stock in working downward cuts cavities into the lining, often forming regular shelves upon which the stocks can easily be hung up. The longer a furnace runs the more favorable it becomes to "scaffolding," and when it is stated that ore is an element which becomes gummy and swollen before it melts to a fluid state, the founder can readily perceive why much trouble can be expected from "scaffolding" and "slips" in a furnace, causing an irregularity in the product and often disarranging all calculations of the furnaces in obtaining the character of iron desired. These conditions alone should enable the founder to perceive that relying on any special brand being always the same from any furnace is very uncertain.

The construction and principle of furnace tuyeres are shown at B, Fig. 5. For the size of furnace shown, eight tuyeres are evenly divided around the circumference and project from 6 to 10 inches beyond the lining.* These are for the purpose of aiding the blast to reach the center, and also protecting the lining. A tuyere protruding no farther than the face of the lining would rapidly cut out the brickwork at that point. There is much importance to be attached to this method, for in my experience with cupola work I have found, by experimenting with tuyeres protruding into the cupola with a design of bringing the blast pressure more to the center (see Chapter XXIII.), that the lining was not burned out nearly so rapidly as with the tuyere's face even with the lining, as is the general practice.

These furnace tuyeres are made of an alloy chiefly

* The present tendency of furnace construction is toward larger hearths, narrower and lower boshes, increased height, smaller tops and bells, and a larger number of tuyeres.

composed of copper, so as to approach a bronze metal. This class of metal has been found good to prevent the melted iron, as it drops down, from adhering to or clogging around the tuyeres, which, if it should occur, would be very troublesome and liable to cause much damage.

When tuyeres are found leaking, it becomes necessary to pull them out and replace them with new ones, which are always previously tested by water pressure to learn if they are sound. There are several ways a furnace-man can tell if water is leaking into his furnace. The plan generally followed to first locate a leak, is to insert a rod of iron through a peep hole A. If upon withdrawal moisture is found on it, leakage is then known to exist. The plainest evidence

FIG. 5.

of a large leakage is an excess of gas in the hot-blast oven, by some called "wild gas," or by steam escaping outward from the furnace at the point of leakage, or, third, by the fact that the iron produced is up in sulphur; and often, instead of the furnace producing a No. 1 iron as desired, it may range from a No. 2 up to "white iron." To prevent these tuyeres from melting or burning away from exposure to the heat of the fuel and hot blast, a constant stream of cold water flows through them, going in at H and coming out at P. Often through irregular workings, tuyeres may become bunged up as in cupola practice, and the method generally followed to open them is to shut off the blast and endeavor to knock a hole through the chilled material, after which the hot blast (of about 1000 degrees heat) with its high pressure, which ranges from 6 to 24 pounds, instead of 6 to 20 ounces, as in cupola practice, will generally cut or burn away the chilled material fronting the tuyeres. Should this fail, the blast is shut off and the tuyere is pulled out, thereby leaving a big hole to work through, and by means of sledges and steel bars an opening is cut into the furnace and the cold, chilled debris pulled backward out of it.

In replacing such a tuyere, a large lump of clay is pushed forward into the face of the hole, and then the tuyere is pressed or knocked inward against the pressure of the stock in the furnace until it is in its right place. After this is done, any clay that might block up the hole in the tuyere to prevent blast to the furnace is broken away by means of a bar, and after the water pipes are attached, the blast is again put on. The reason for first pressing the lump of clay into the

furnace before inserting the tuyere is for the purpose of protecting the tuyere from the melting heat of the furnace until it can be properly replaced and water attachments reliably made. The removal or insertion of furnace tuyeres is an operation very readily performed, owing to the taper seen in the stationary sleeve at T, Fig. 5. This stationary tuyere support is cast hollow, of the same metal as the tuyere proper, and is kept cool by a flow of water going in at W and coming out at F. It is very rare that one of these sleeves is required to be removed, as they do not project into the furnace, as is the case with the tuyere proper.

Coolers. It is very important in furnace construction to provide means to keep it cool, as this is a necessity to long continued running. Some furnaces are better provided with cooling appliances than others. In the furnace shown, water is admitted to a suspended cast-iron receiver (as seen at X), which encircles the furnace, excepting an opening of about two feet at the front or breast side of the furnace. The cold water is admitted to this receiver in its lower division at M, and after having done its work it flows into the upper division and is carried off through the waste pipe N. The pipes marked Y are those admitting the cold water to the coolers, and P those returning the heated water to the waste receiver. At V V V are seen some of the many coolers which are built in the furnace lining to preserve its life. In the furnace shown these are placed in layers about 30 inches apart in height, and has about two feet of space between them. Some furnaces have them built much closer than this, both in height and circumference. There are various plans of coolers used with furnaces. The coolers

here illustrated are made of cast-iron about three inches thick by two feet square, and each has three independent coils of one and one-half inch pipe cast in it, so arranged that should the front coil be attacked by the heat as it burns out the lining, it can be shut off, and the inner coils be made operative independently or as a whole. Some furnaces have these coolers made of bronze, cast hollow. It is very seldom trouble is experienced with the coolers shown, and if any should occur arrangements permit their being taken out and replaced. At L is seen a two-inch pipe, perforated with one-eighth inch holes about two inches apart, which encircles the furnace and keeps a constant stream of cool water running down the plate I which supports the hearth portion of the furnace. This water runs down on the outer surface of the plate to a reservoir R, which can be filled up with water to a height of three feet, should it be found necessary to protect the lower portion of the hearth with a heavy body of water. A valve is so arranged in this lower reservoir R that any height of water can be maintained. It is no unusual occurrence for the metal to break out at this portion of a furnace, resulting in much danger to life and property. The furnaceman's lot is by no means one the founder need envy, for he shares very fairly the troubles and dangers he has who "meddles with hot iron."

No boiler casing or shell is used to support that portion of the hearth and bosh which inclose the tuyeres and water coolers V. This portion of the furnace has its fire-brick work supported only by means of wrought-iron bands, six inches wide by one inch thick, which encircle this portion at the height of

every two feet, as seen at S. The idea of not encasing this part with solid boiler plates riveted together, as is done with the balance of the furnace, is so as to permit this portion of the furnace brick-work to be exposed to the cooling influence of the atmosphere all that is possible. It is at this unprotected part of the bosh and hearth that the lining is subjected to the greatest heat, and hence the reason for the arrangement of coolers and exposure of the outer surface of the lining as has been described. There is reason to believe that attention will be paid by founders to the matter of providing arrangements for protecting the "melting point" of a cupola, and the principles herein described cannot but be of much assistance in aiding to form ideas for such appliances. While there are specialties in founding to which these ideas will be of little or no value, still we have, even at the present day, some that could well use such appliances for keeping cool the "melting point" to good advantage. There is a tendency in some lines to attain continuous melting, and with such these ideas cannot but be of value. As an amusing incident, the writer some time back witnessed a heat being run in which three men with buckets and one with a hose were throwing water on a cupola shell to keep it from burning out until sufficient iron could be melted for a big casting which was to be poured. Were this founder aware of blast furnace practice, he no doubt would feel like utilizing some of its cooling appliances as a labor-saving device, should he have another heat under the same conditions.

CHAPTER V.

BLAST FURNACE vs. CUPOLA PRACTICE.

FOUNDATION, LINING AND DRYING OF FURNACES.

Foundations should be carried down to a depth leaving no doubt as to their ability to prevent any leakage. It has been, and is yet with some, no uncommon occurrence for foundations to spring or settle so that when the furnace is tapped with the expectation of obtaining from twenty to sixty tons of metal to be run into pigs, to find it has all disappeared. Not long ago, a furnace in the writer's section ran for about two days in an effort to supply the cravings for space under its foundation. When the great head pressure of stock, ranging from two to four hundred tons, weighing down on a molten mass, is considered, it is very easy to conceive how the least crack in a foundation can permit the weight of stock forcing all the metal in a furnace to penetrate or find any weak spots in the ground below its foundation or in the sides of the hearth. The rapidity with which metal will bury itself in coarse gravel or sandy earth, when once started, is amazing. In the first days of furnace practice, the necessity for good, deep foundations was not realized as at the present day. It is doubtful if excavations were then deeply made under any of the furnaces, and it may be that if at the present day they were deeply

undermined, from one hundred to five hundred tons of iron would be found. Past experience, dearly bought, has taught the furnaceman to provide reliable foundation. In some localities the depth required is greater than in others, and in some cases even piles had to be driven before the foundation is started. In the furnace shown, Fig. 5, page 53, the stone-work illustrated was about five feet deep, on top of which a bed of fire-brick about six feet deep was laid, before the bottom or bed of the furnace was reached. Such foundations are costly, but it has been found wiser to have capital lying idle in them than in iron that could never be brought back to earth.

Long durability of linings is evidenced by the fact that blast furnaces have run steadily in America for over five years and in Europe fifteen years and over. The cause for such a difference in the life of linings between the two countries is due to the greater driving or blast pressures generally used in America to obtain a larger output of iron. The chief element necessary to protect and give life to a furnace lining exists in the formation of a kind of graphite or carbonaceous concrete which accumulates on the face of the fire-brick. This comes from the kish, slag and carbon dust generated in the furnace, which may be found 2 inches to 12 inches thick on the lining, the greatest thickness being found in the heart or lower part of a furnace.

The great life which has been secured to furnace linings in either country is far in excess of that which can be obtained by any possible means at the present day in cupola practice, and in a practical way is due, first, to the formation of carbon kish on the lining; second,

to the protrusion of tuyeres to carry the blast's greatest force beyond the face of the lining, and third, to the constant, steady temperatures contained within a furnace. While the founder cannot achieve the first and third elements, he can assist in prolonging the life of cupola linings by following the methods outlined in Chapters XVI. to XXIV., which mainly advocate "center blast" practice for cupola work.

The chemical actions taking place to destroy the life of furnace linings are defined under four heads in the Iron and Steel Institute *Journal*, 1878, vol. 1, p. 200, by Fritz W. Lurmann, as follows:

"1. The actual wear due to contact with the descending charge. This is relatively unimportant. 2. The actions of the alkaline cyanides and other substances present in the furnace gases which, though probably important, produce an effect the amount of which is at present not accurately determined. 3. The action of sodium chloride or other alkaline substances contained in coke; this is probably one of the most important causes of wear, as at a high temperature salt is decomposed by silica, and a fusible silicate is obtained. 4. The flaking of the bricks due to deposition of carbon from carbon monoxide around any iron particles reduced from impurities in the original bricks."

Absolutely fire proof bricks, it can be said, are not obtainable. Several different kinds of material have been tried in an effort to secure a lining for furnaces and cupolas that would exceed the life of the general character of fire clay bricks used. We have what are called silica, carbon, ganister, coke, magnesia and asbestos bricks, all of which have been experimented with, and to a degree have advocates for their utility in certain lines of work. Carbon bricks, it is claimed, have stood well, made of fine coke (poor in ash) or charcoal, mixed with clay, having tar as a binder.

After the coke is dried, pulverized and sifted, about 20 per cent. of tar is mixed with it and the plastic mass then pressed into brick moulds, which are allowed to dry in the moulds for about fourteen days, after which they are burned without access to air.*

High silica bricks are often used for high temperatures, but if such bricks contain more than 70 per cent. of silica they are generally very friable and disintegrate with the least friction, so that bricks of this character would only be suitable for the lower body of a furnace or cupola. Silica is a pure oxide of silicon, of which white sea sand is an example, and requires plastic clay to be mixed with it as a binder. As clay is chiefly composed of alumina, which is also an element nearly equal to silica in resistance to high temperatures, it works well as a binder with silica in making fire-bricks. Some claim to mix silica as high as 90 per cent. with alumina as a binder. There are other elements in clays, such as iron oxide, lime, magnesia, potash and soda, most of which, to some degree, serve an end in increasing the durability of fire-bricks. As fire-bricks come to the furnace or foundry, they are generally composed of about equal parts of silica and alumina. The bricks can be chiefly of aluminum or silica, just as they are required to stand heat or friction. The purity of these two elements has all to do with the life of fire-brick. The silica should be of pure quartz or anhydrous silica and not of calcined or raw rock for a substitute, as is often practiced by some. It can be readily seen from the above that one kind of fire-brick may give excellent service with one firm or character of work and be utterly worthless for other places.

* *Journal* of Iron and Steel Institute, 1891, vol. 2, p. 240.

Because lumps of dried clay may be called fire-bricks is no reason why we are to expect all such to give like good service under all conditions.

Chemical analyses of clays or fire-brick are as essential as are the irons which the founder may use, if he expects the best results in their use. Chemistry can serve as good an end to the furnaceman and founder in defining what elements should exist in fire-bricks as it can in any other fields of their practice, and the day is fast coming when they will demand an analysis of fire-brick similarly as they will of the ores or irons they may use in their daily practice.

Shapes of bricks and methods of lining a furnace have as much to do with the life of the lining as other qualities defined in this chapter. It is a costly affair to line a modern furnace, and when completed it should give at least a continuous service of two years with hard ores and three years with soft ores, and this length of service may be often doubled. When it is stated that 450 tons of fire-brick and 60 of fire-clay, or a heavily laden train of about twenty-five cars of material, are necessary to line such a furnace as seen in Fig. 5, the magnitude of such a job, as compared with lining even our largest cupolas, can be readily perceived. Bricks for a furnace are largely made to order, so as to neatly fit its curves, slant or circle, which the form of the shell or inside of the lining, etc., might exact. This is done so as to have all joints fit as closely as possible without cutting bricks or filling in with clay. Bricks for the hearth and bosh are desired of a softer quality than those used for the stack portion of a furnace, as the latter are exposed to greater destruction from friction, while those in the hearth

and bosh portion are chiefly subjected to the action of heat. Such a quality, if used in the stack portion, though its composition is best able to withstand the heat, would soon wear away by the constant friction of the stock working downward, so that better service is found by sacrificing the heat qualities to those best calculated to withstand friction for stack linings.

In laying bricks, a thin grouting of the best fire-clay, without mixture of sand, is used. The clay is mixed of such consistency that a brick, if dipped into it, would, upon being lifted out, have a coating of about one-eighth of an inch adhere to it. To make a bed of clay for the brick to be laid in, a dipper is used to pour the clay upon the surface of the last course laid to a thickness of about one-fourth of an inch. The bricks are then slid on soft clay up to each other so as to imbed themselves firmly and closely force the clay between all joints, after which a hammer is used to crowd the joints still more closely together and bed the bricks more firmly, if such a thing is possible. In order to obtain a true circle when lining the hearth, bosh and stack of a furnace, a plumb bob-line is dropped from the top to obtain a center for a "spindle" with a "sweep" attached, to be carried up as the work progresses, just as a loam moulder would build a large cylinder mould. The number of men generally employed in lining a furnace is about four masons and twelve helpers. The time usually occupied to line such a furnace as shown in Fig. 5, with the above number of men, is about thirty days. The work of lining a furnace is considered a specialty, and the leading men in such work are carefully selected from those

having the greatest experience in this line, as any faulty construction can easily result in a very short run of a furnace, thus causing a great expense in "blowing out" to remedy the evil.

Space for expansion of fire-brick, as illustrated at K, Fig. 5, and both sides of Fig. 6, page 71, is a practice now followed in lining furnaces. This space ranges from three to four inches in width, and in length from the bosh portion up to the top of the stack, as shown, the hearth being built solid, as seen in the sketch. A material now greatly used for filling this expansion space, K, is the slag of a furnace, after it has run over ditches of water, which action "foams it up" and destroys its compact composition, thus making it of a light, porous character easily admitting of expansion from the lining when it is packed in the space K. This space is carried upward as the lining progresses. A loamy sand was at one time used, but was found to pack too firmly. Then, again, a coarse class of sharp sand has been used, but the slag as above prepared has been found the best. Experience has proven the necessity of such a system, as several furnaces have had their shells ruptured by the expansive force of fire-bricks when not permitted room to swell from the effects of the heat. Not only have furnaces provided for this lateral expansion, but also for longitudinal strains as well, as such action has been known to press the brick-work, bell, hopper and charging platform upward from three to four inches above the top of the shell, or its original level. All the iron work at the top of a furnace is constructed independent of the shell, so as to liberate it from all strain when longitudinal expansion takes place.

The principle involved in providing for expansion in furnace practice proves that the practice of contracting the stack of cupolas followed by most founders is not the best, especially where the contraction begins from the body of the cupola to the stack, but a few feet above the top of the charging door. When we consider that in cupola practice "heats" are not continuous, but generally last only a few hours, after which the cupola cools down as suddenly as it was heated up, thereby causing an action of expansion and contraction at every "heat," it seems reasonable to conclude that where expansion is not allowed, such a factor would be about as injurious to fire-brick exposed to the heat in cupola work as in furnace practice. As founders, we often find trouble with the brick-work being loosened or scaling off around the jambs of charging doors and the surface of the circle at that portion of the lining. In many cases such wear-and-tear is not all to be charged to rupture from throwing in the stock to charge the cupola. If there is any excessive crushing pressure on the bricks at this point due to their expansion, it is certain that jars and blow from stock being charged are aggravated by expansion in the brick in bringing about the final rupture. Furnacemen have been taught to allow for expansion by very radical and costly demonstrations, and it does seem that the principles involved are worthy of some note by the founder who is desirous of obtaining the best wear possible from a lining.

Drying a furnace, as in cupola practice, becomes necessary before it is charged for "blowing in" after it has been lined. There are several ways used to achieve this end. One is by building a fire inside the

furnace; another by constructing a fire-place outside, at the breast portion, and letting the heat from the same pass into the furnace; still another by the admission of natural gas, or the gas from the ovens of another furnace, should two or more furnaces be near each other. Where there is no opportunity for obtaining gas, the plan now generally followed is that of building a fire-place about four feet square, arched over with brick and having a good ash pit below the fire-place; a strong fire in such a construction is very effective in rapidly drying out a furnace. The objection to building a fire inside a furnace is that the dirt and ash which it creates require considerable labor for cleaning it out. After a fire has been well started, all holes around the furnace and the top, with the exception of a "bleeder" of about twelve inches diameter, are closed, the "bleeder" being left open to create draft. The length of time required to dry a furnace out thoroughly ranges from two to four weeks, but we have furnacemen who have started a furnace without drying and exulted over the same as being an advance in furnace practice. The writer's experience in cupola work would lead to the conclusion that to start a blast furnace without thoroughly drying it is not good practice, and where this is done it is at the sacrifice of the lining and the quality of the iron produced for several days' runs. A furnaceman can, of course, start his furnace without drying it, but the author fails to perceive wherein he has anything to boast about in the way of an achievement. All heavy-work moulders well know that if there is any extra dampness in the green sand moulds, or if a loam and dry sand mould is not well dried, the liquid iron when

poured into them will create a steam which, to find relief from expansion, will force itself to the surface of the mould, bursting and scaling off the same in the form of blacking or sand scabs. Steam confined in fire-brick work cannot but be injurious to a greater or less degree in rupturing the face of a lining as well as that of a mould. The founder also knows that if he attempts to run a heat from a fresh-lined cupola without first having thoroughly dried the brick-work in the same, he will secure a very dull, poor quality of iron from his mixture, and the next morning when cleaning out the cupola will find that the previous heat has burned it out more, in many cases, than a three months' run would have done had the cupola been properly dried before the first heat was taken off. The advocates of thoroughly drying the lining of a furnace can easily find evidence to support their position, whereas the few advocating no drying cannot furnish any practical results as evidence to prove that such a practice is a wise one or in any way economical.

The wear of cupola linings is very short compared with furnace work and calls for an explanation of conditions which differ in cupola practice versus furnace work, and which, when intelligently understood, may aid many to obtain better service from their linings than they do at the present day. The first element which is disastrous to the founder in such a contrast lies in the fact of his being compelled at every "heat" to subject his lining to a sudden rise and fall of temperatures, for at the end of every "heat" present practice compels him to drop the cupola's bottom, which operation suddenly cools off the lining. This sudden cooling is so sharp at times, in cold weather, that the

cracking of the brick-work can be distinctly heard for an hour or so after the bottom has been dropped. The effect of such sudden cooling is as detrimental to the life of the lining as the sudden heating up which a cupola receives when fired at the commencement of every "heat." The evil of such sudden contraction and expansion cannot but be evident to any observing founder, and suggests to him the advisability of starting his fires and blast at the commencement of a heat in as moderate a manner as possible. It also demonstrates the undesirability, when dropping a bottom, of deluging the refuse with water until every vestige of fire is obliterated. Again, it is not calculated to encourage the practice some founders have of instructing the night watchman to occasionally douche the inside of the cupola during the night with water, so as to make it nice and cool for the cupola man to get inside the next morning. If such cooling is necessary, the better plan is to pull the droppings out from under a cupola in the evening, when the bottom is dropped by means of the refuse dropping on a grab hook to be pulled out by power.

The second element in the destruction of a cupola's lining is due to having too strong a blast; and again, the same pressure with two cupolas of like dimensions can work very well with one, while with the other it may prove very destructive. The quality of the iron and fuel used, and the variations that may exist in the form and size of blast pipes and tuyeres, and the distance of the fan or blower from the cupola, have much to do with different results in two cupolas of like size.

The third element disastrous to the durability of a

cupola lining lies in not properly "daubing" up a cupola in preparing it for "heats;" but as the author has dwelt on this factor in other writings, he would refer any desiring information on this point to pages 307 and 314, "American Foundry Practice."

CHAPTER VI.

BLAST FURNACE vs. CUPOLA PRACTICE.

CHARGING, DESCENT AND REDUCTION OF STOCK.

During twenty-four hours there are charged into a furnace the size shown in Fig. 6 about 280 tons of ore, 190 tons of coke and 60 tons of limestone, a total of 530 tons of material passing through the furnace every day, producing daily about 165 tons of iron. In charging the furnace, two gangs of men are employed, one at the top and the other on the ground floor, loading the buggies and wheeling them to the elevator, which descends a distance of 70 feet in about twenty seconds. There being two cages to the elevator, an empty one is returned as the loaded buggy ascends. The buggies hold about 800 pounds of ore, and of coke 450 pounds. The men charging the furnace are called "top fillers" and those loading the buggies "bottom fillers." The work is thoroughly systematized, each man knowing his part. Top fillers hold a somewhat hazardous position, as it is no uncommon affair for men to be "gased" by the fumes escaping at the bell and hopper of a furnace. Some furnaces suspend a sheet iron stack about ten feet over the top of the bell, on the charging platform, for creating a draught to lessen the volume of gas.*

Improvements have been recently made at Carnegie's furnaces, whereby all stock is carried up and dumped by machinery into the hopper, so that there is no need for men working on a furnace as "top fillers."

In charging the stock, the coke, limestone and ore are generally dumped in the order mentioned and dropped independently of each other in the hopper H, Fig. 6. After the completion of each charge, the bell B is then lowered as indicated, and the material falls down in the furnace shown, about as illustrated at the mound M M. After the delivery of the charge, the bell returns to its position, ready to receive the next supply of stock. There are several ways of operating the bell, but the method used with the furnace shown is that of moving the beam S up and down by means of a cylinder D, which can be operated by steam or the blast pressure. The bell must be hung true, since, if one side should swing lower than the other, when

FIG. 6.—ACTION OF STOCK DESCENDING A FURNACE.

the stock is admitted to the furnace, the charge would lodge unevenly and have a tendency to assist scaffolding and cause evil results similar to uneven charging of stock in the cupola.

All material that is charged into a furnace passes off either as a liquid or as a gas. The gas chiefly escapes at the top, passing through the "down-comer" to the ovens to heat the air, which is driven through the pipes on its passage as blast to the furnace. The liquid elements pass off as iron or slag, both formed at a point ranging from a level with the tuyeres to a height of four feet above them, which latter is generally called the "melting zone," the hottest part of a furnace. As the coke, limestone and ore settle in their descent, any moisture that may exist in the stock is first driven out. Then the stock becomes rapidly heated and in its passage downward to what is called the reduction zone, the largest diameter portion of a furnace, it becomes plastic, and as it proceeds, is melted and falls in a fluid state to the bottom. The non-metallic or earth matter, in separating from the ore, is absorbed by the lime and, being lighter than iron, floats on its surface and is tapped off as slag through the hole T, Fig. 6, while the iron is delivered at the tap hole X.

According to the nature of the ore charged, certain pressure and temperature of the blast, as well as percentages of fuel and limestone, are necessary to attain the best economy in fuel and output and bring down the latter as a high-grade iron. If the blast pressure is too high, it forces or drives a furnace so as to bring the stock too rapidly to a plastic state in the upper zones to give time for a proper reduction of the ore be-

fore reaching the "melting zone." It may also be said that the excess of air or oxygen, which cannot be best absorbed by the fuel or its carbon, will, by reason of its being of a much lower temperature than that of the furnace, only rob the fuel of heat in order to raise the excess of air to a higher temperature than that at which it entered the furnace, and results in cooling the furnace down and giving a product called "cold iron," and often a low grade of iron. We have but to study furnace practice in this line to show us that there is such a thing as having too little or too much blast in a cupola, and that we can partially regulate results when melting by an intelligent knowledge of the effect different degrees in blast pressure can have. For more information on this question, see Chapter XII.

If ore is not properly reduced, a percentage of its iron may pass off with the slag. The reason for this is that it is not thoroughly extracted from the non-metallic matter of the furnace, and what iron is obtained is lower in silicon and higher in sulphur. This is explained by the fact that the heat of the furnace is insufficient to reduce the silica in the ore and fuel to the degree it is when the furnace is working hot. The silica in the coke or fuel is what causes the silicon in the iron, and the hotter the furnace can be made the more silicon will the pig metal contain, other conditions being the same. As silica is a very refractory material, hard to melt, it can be readily perceived why a cold furnace would generally give lower silicon in the iron produced. Carbon in iron is obtained from the fuel of a furnace, and the same can be largely said of sulphur. Iron in the ore, as well as the limestone

used to flux it, absorbs sulphur. Which of these two elements in the process of reduction will absorb the greater percentage of sulphur from the fuel depends upon the degree of heat each possesses. Lime has a great affinity for sulphur, and if it is reduced to make a thin and hot slag it will greatly rob the iron of its share of sulphur; but if the furnace is working cold, so as not to properly flux the limestone, then the iron will absorb and retain higher sulphur, and hence the greater sulphur found in iron coming from a cold working furnace, which often results in giving a hard or "white iron." The way high silicon and low sulphur iron, or No. 1 pig iron, is generally obtained is by having a hot furnace well, but not excessively, fluxed with lime. To make high silicon and high sulphur iron, as is often obtained, and such as can be a No. 1 or 2, but more generally a No. 2, it is necessary to have a hot furnace poorly fluxed with lime. A cold furnace gives a bad, thick slag, the same as a cold cupola retards good fluxing or slagging out. A good working furnace sends the silicon into the pig and the sulphur into the slag; a poor working furnace sends the sulphur into the pig and the silicon into the slag.

Furnacemen have their own ideas as to the "lines" of a furnace best calculated to achieve most desirable results with special ores. There is no end to the different angles, etc., given to furnaces, each style having its advocates, until at last we have Hawden and Howson, of Middlesbrough, England, who are advocating and using a plan of turning present forms upside down. This plan, at this writing, has proved so successful with the kinds of ores used that several new plants are being erected in England. We might also

mention that even strictly straight furnaces have been tried, but these, it is said, have proved a failure, as a study of these pages would lead us to believe. There are over 500 blast furnaces in the United States to-day, and nearly all of them differ more or less in their "lines," etc. Since the publication of Mr. James Gayley's valuable paper on "The Development of Blast Furnaces," read at the New York meeting of the American Institute of Mining Engineers in October, 1890, the "lines" now generally adopted in this country for coke furnaces are more in accordance with those outlined in the Edgar Thomson furnace "F," at Braddock, Pa. (also shown in Fig. 6), in which the hearth is about half the diameter of the largest part of the bosh, and the throat or top of the stack about two-thirds of the bosh's largest diameter, in a height of about 80 feet. Furnaces having the largest hearth and the greatest distance between the cinder notch and tuyeres are claimed to be making the greatest tonnage.

In reasoning out the action of stock in passing down through a furnace, it would seem desirable to attain, if possible, an occasional shifting movement, so as to retard the formation of any solid union of the stock. This is best achieved with a taper stack, as the stock in passing downward should assume an action somewhat similar to that illustrated in the various levels, A, B, C, D, E and F, seen in Fig. 6, page 71. When stock is dropped by a bell, such as in the size of the furnace shown, it is generally, if all is working well, distributed in a form somewhat like that in the mounds M M, seen at the level A, which is called the "stock line," and is generally ten feet below the level of the bell. The stock in settling down to fill the increasing diam-

eter of a tapering stack must have a spreading out or leveling action taking place, or in other words, the outside would descend faster than the inside stock. It seems reasonable that the tendency of the stock in settling would be to have the angles constantly leveling themselves somewhat after the idea illustrated at the various strata B, C, D and E, Fig. 6, until it has reached the commencement of the bosh at F, when reaction would take place and the stock in descending would be retarded by the walls of decreasing diameter in such a manner as to cause the center portion to travel faster than the side, until at the last stratum, I, the center stock would have traveled ahead of the side stock as shown at R.

Before this point is reached, however, the stock is generally fluid or has escaped as a gas, since by the time any plastic stock has reached the level at Y the iron has generally been extracted from the ore, and what passes to the point Y is usually in the form of fuel to replenish the "bed" of molten metal in the hearth, or of refuse which will be carried off as slag.

The total lengths of the line at the different levels, B, C, D and E are the same, and the theory of action of descent of stock which the author has advanced herein, he believes, has every basis in good reasoning. In cupola practice we have an advantage over the furnace in being able to observe the action of the stock until it has reached the "melting point." In observing stock settle at the last charge in a straight cupola, when all is working well, little or no change is noticed in the position of the material, and this is generally so true that the founder knows that whatever way stock is delivered into a cupola it will generally be found so

situated when it reaches the "melting point." For this reason we often have experience with "bunged-up" cupolas or iron dumped at "bottom-drop," which could not be melted owing to fuel or iron not having been charged evenly. Often stock reaches the melting point with fuel mostly on one side and iron on the other through carelessness in charging in that manner.

The difference noted in the workings of straight and tapering cupolas, or those smaller at the charging door than at the level of the tuyeres or just above them, would strongly lead a founder to say that the actions above outlined for a furnace are not far from those in a cupola. Iron in working down a tapering cupola is at short intervals changing its lateral position, causing an agitation of the stock and making it in some ways more difficult to wedge or hang itself up than if passing down a straight cupola. Only in the case of excessively bad working, or a very ragged, worn-out lining in a small cupola is there any fair chance for stock hanging in a tapering cupola as it descends to the melting point, where the taper is smallest at the charging door. Were we to reverse the taper so as to have a cupola from its charging door down to the tuyeres like the bosh portion of a furnace, then we would be greatly troubled with stock hanging up. In very large cupolas the diameter is generally the smallest at the tuyeres in order to save fuel, and have blast reach the center with more force. From a few feet above the tuyeres large cupolas generally have parallel sides to the charging door. This plan is an approach to the principle found in the bosh and stack of a furnace, and to a degree works the same in attaining results. Fur-

nacemen claim that scaffolding is generally done in the bosh portion of a furnace. The founder's experience with cupolas brought in at the tuyeres would sustain the common sense of such a claim, also that it was not desirable to make a bosh of too great an angle.

The main study of the furnaceman to-day is the question of obtaining regularity and avoiding slips, and many are of the opinion that such ends are to be achieved as much by the method adopted for charging the material as by the shape of the furnace "lines."

Where the bell and hopper are used for charging stock, the angle and diameter of each, as compared with the diameter of the furnace at its throat or stock line, have all to do with the form and position which stock assumes when dropped into it. The angle of the hopper influences that of the bell in determining the distribution and position of coarse and fine material, also the formation of the irregularities in mounds which a charge may assume, after being dropped by a bell into a furnace. It would not be a bad idea for furnacemen to test the actions of such angles by means of inclines formed of boards or sheet metal with the actual stock intended for use before deciding on the angle and diameter of the hoppers and bells. By such a test a furnaceman could then learn very closely the manner in which the stock would be delivered, an element which now seems to be largely one of guess-work. It is generally conceded that the small bell, as in Fig. 7, sends the coarse material to the outside circle, while the larger bell, Fig. 8, sends it to the inner circle, and the coarse material will descend faster than the fine stock. Furnacemen are now largely adopting small bells.

Some years ago, Professor Richards, of Boston, made

a model of a furnace having a glass front, so that the action of stock in descending a furnace might be observed. The material which was selected to represent ore, lime and coke was taken out at the bottom and filled in at the top. Much was claimed for the experiments in showing the true action of stock in descending a furnace, but after the professor had brought his experiments to the notice of English furnacemen it was found that Sir Lowthian Bell had previously experimented with a similar device; but the opinion seems to prevail that while such a model was very instructive, still through the lack of conditions as regards heat, etc., not being present, it was at its best not of the value expected in demonstrating the true condition which actually existed with stock in descending a furnace in general practice.

FIG. 7.

There are three elements affecting the descent of stock and preventing slips, which is the great evil all aim to over-

FIG. 8.

come. The first of these is the lines of a furnace; the second, the manner in which stock is delivered or charged, and the third the quality or nature of the ore and fuel used. A few years ago experts said that the Mesabi ores could not be smelted in a furnace, owing to their being so fine and loamy. But the large percentage of iron which they contain, their low phosphorus (making a good iron for Bessemer pig) and little sulphur, three very desirable elements, combined with low cost, caused furnacemen to try it and persevere in its use, until to-day it is a large percentage of the ores charged into many furnaces. Nevertheless, furnacemen are finding much trouble from slips and wastage of ore in the form of fine dust being carried out with the gases through the "down comers." There is much study being given in hopes to devise methods to overcome the difficulties encountered.

A late plan now adopted by some furnaces in order to work Mesabi ores is that of decreasing the diameter of the hopper and bell. A few who have taken out their old bells and replaced them with smaller are said to report a very commendable improvement in preventing slips when using Mesabi ore. The action of the small bells causes the fine material to occupy the central portion, and the coarse the outer portion of a furnace, something after the plan seen in Fig. 7. The reverse action caused by the use of a large bell is illustrated in Fig. 8. This method of arranging the fuel more to the outside and the ore to the center, brings to mind a similar plan which has within a year been tested in remelting iron in a cupola, and which is a very radical departure from any past practice, and

was invented and patented by Mr. W. H. Bradley, of Mingo Junction, Ohio.

Mr. Bradley's plan of a cupola is to keep the iron and fuel separate, the iron being in a solid column in the center, with the fuel encircling it at the bottom for a few feet in height, and the fuel bed under the iron the same as in present practice. In order to keep up the "bed," in all past practice it has been done by charging the fuel with the iron in alternate layers. Instead of replenishing tne "bed" by carrying the fuel down between layers of iron, Mr. Bradley's plan is to charge the fuel into shutes encircling the outside of a cupola, which carry the fuel down to replenish the bed as seen at A and D, Fig. 9. The opening of the shutes is level with the charging platform, as seen,

FIG. 9.—BRADLEY'S CUPOLA.

and to regulate their delivery of the fuel to the "bed" and the escape of gases, dampers or valves are used at the lower portion of the shute where it enters the cupola. The iron is charged through the charging door as in ordinary practice. The cut, Fig. 9, should at a glance afford a knowledge of the general principle involved. Mr. Bradley has at the steel works of which he is superintendent an old cupola which was remodeled so that the principle claimed in his method could be tested. Mr. Bradley claims that a comparison of the records of the old and new methods shows quite a saving in the fuel, destruction of lining, oxidation of metal, and in obtaining a good slag. This new plan is a radical departure from all past practice. There is one thing certain: if it achieves what Mr. Bradley claims for it, there is a very strong probability of this principle displacing much of our present practice, especially where long heats or continuous running is desired, and I would think "center blast" would work excellently with Mr. Bradley's cupola.

There are many ideas suggested and a strong relation to be found in the principles involved in the distribution of stock illustrated in the cuts, Figs. 6, 7, 8 and 9, going to prove that there are many things that work similarly in a furnace or cupola, and that a knowledge of these principles in the working of a furnace can ofttimes be well utilized by the founder, who in turn may present information of some value to a furnaceman.

CHAPTER VII.

BLAST FURNACE vs. CUPOLA PRACTICE.

CREATION OF SLAG AND FLUSHING OUT.

Ten to thirty per cent. of the ore and ten to fifteen per cent. of the fuel charged into a furnace are composed of earthy matter and ash which must be carried off as slag. This extraneous matter is either basic or acid in its nature, each possessing strong affinity for the other, so that when subjected to high heat their union causes the whole to be reduced to a fluid state. As a general thing, the percentage of basic property in the refuse is not sufficient in its action on the acid element to reduce the whole to the fluidity necessary to make it flow freely, or properly extract all extraneous matter from the ore. To remedy this defect, limestone is generally added to all charges of ore going into a furnace. While the lime assists in fluxing the earthy matter or refuse in a furnace to the state of fluidity required, it also affects the quality of the iron produced, as described in other portions of this work.

Furnacemen can fairly tell the grade of iron to be produced by the color and nature of slag "flushed" from a furnace before the iron is tapped. If a lump of solidified slag, when broken, presents a black color, very dense in its composition, it denotes the produc-

tion of a low-grade iron, or iron very low in silicon and high in sulphur, with high iron in the slag. If slag is of a light or gray color and its fracture presents a porous composition, it is generally an indication of a high-grade iron being produced, well up in silicon and low in sulphur and low iron in the slag. Degrees in color and solidity of the slag between the two extremes vary according as there is a difference found in the grade of the iron. The use of high manganese or manganiferous ores generally gives either a green or brown slag. A green, glassy slag from such ores indicates that the furnace is working well, but a brown slag denotes the reverse. These grades of slag are generally produced in the making of spiegeleisen and high manganese iron.

What is termed "scouring cinder" is generally the worst slag which comes from a furnace. It is of a reddish brown color and is chiefly caused by a slip or some bad working of a furnace, causing ore to pass down to the fusion zone in an unreduced state. This class of slag is quite cutting on the lining of a furnace, owing to its containing so much oxide of iron and being very basic, a combination most effective in dissolving the silica in the bricks forming the lining.

Basic slag is white and dense and requires a high temperature to fuse it. Foundry irons generally give a slag more silicious or "stony" than that coming from Bessemer iron.

Not only is it the office of slag to assist in separating the earthy matter from ore and in carrying the same off from a furnace, but also to absorb sulphur and thus greatly retard its being taken up by the iron. While lime is the chief element in a flux causing slag

to take up sulphur, protoxide of manganese is also very effective to this end. The presence of high lime in slag is generally exhibited by the slag having a dull, stony white nature. Slag of this composition will often fall to pieces of its own accord and form a fine dust similar to that of lime slaking itself when exposed to moisture. Slags of this character on being subjected to wetting will often form a very compact, solid body admirably adapted for road-beds. Such a quality in slag generally denotes a high-grade iron and that the furnace is working hot, whereas slag that is not readily broken and is black in color denotes low-grade iron and that the furnace is working cold, or has a low temperature. Slags high in lime require a higher temperature to melt or fuse them than if the slag contained more of protoxide of iron. The greater the percentage of the protoxide of iron slag contains, the more dark and dense it is, owing to its being high in iron, as shown above.

Analyzing slags is now taking the place of judging by their color, etc., as a guide in deciding what may be expected in the grade of iron to be produced. In some instances there are conditions which can cause the analyses or appearance of slag to be deceptive, in respect to giving assurance of the quality in iron to be produced. One of these lies in the slag being tapped before the iron, and thus affording time for conditions to sometimes change in a furnace, resulting in an alteration of the composition of the iron before it is tapped from what the slag would indicate. This quality, in connection with others, makes the judging of iron by the character of the slag produced often a very uncertain matter, very deceptive to the furnace-

man. Some furnacemen are having their slags analyzed at every "cast," as a guide to assist them in regulating the furnace, and, as long as it works normally, this proves a very satisfactory guide in fairly assuring a furnaceman as to the character of the iron he may expect, or whether any changes are taking place which would call for an alteration in the manner of charging or working a furnace. This plan of taking analyses of slag has proved a great improvement over guessing at its quality by the color, etc., as has been the practice in the past.

To afford some knowledge of the relation which chemical properties in slags bear to the iron produced, the analyses in Tables 10 and 11, obtained by the author, are presented:

TABLE 10.—ANALYSIS OF FOUNDRY IRON.

Silicon.	Sulphur.	Manganese.	Phosphorus.
2.09	.013	.25	.769

TABLE 11.—ANALYSIS OF SLAG.

Silica.	Alumina.	Lime.	Manganese.	Magnesia.	Iron.	Total.
33.08	19 74	44.74	.11	1.44	.40	99.51

Table 12 is slag selected from different authors to present a knowledge of the character of slag from different ores and classes of fuel. The first and second columns are slags produced from raw coal smelting at Dowlais, Wales, presented by Riley. The first column is a slag from gray iron and the second from a white iron. The third column is a slag from coke with Cleveland ores making gray iron, by Bell. The fourth is from anthracite, making gray forge iron, at

Bloomington, N. J., and the fifth is from charcoal iron made at Josberg, Sweden, by Sjogren.

TABLE 12.—ANALYSES OF BLAST FURNACE SLAGS FROM DIFFERENT ORES AND FUELS.

	1	2	3	4	5
Silica	38.48	43.07	27.68	42.17	61.06
Alumina	15.13	14.85	22.28	13.59	5.38
Lime	32.82	28.92	40 12	33.02	19.81
Protoxide of Iron	0.76	2 53	0.80	1.28	3.29
Manganese	1.62	1.37	0.20	0.27	2.63
Magnesia	7.44	5.87	7.27	8.31	7.12
Sulphide of Calcium	2.22	1.90	2.00	0.64	......
Alkalis	1.92	1.84	......	......	......
Phosphoric Acid	0.15	......	......	......	......
	100.54	100.35	100.35	99.23	99.29

Slag contains sulphur and silica, with the former generally ranging from 1.00 to 2.00. The smell of sulphur is sometimes very strong from slag when a furnace is being flushed. This fact would go strongly to confirm the advisability of melting iron hot in a cupola, in order to lessen its sulphur where this is desired. Another point to which the writer would call attention is the percentage of silica the slag contains, going as high as 60.00, as seen in Table 12, showing us ways in which silicon can be carried off or reduced as silica in smelting and re-melting iron. It is claimed that the amount of silicon would be reduced or oxidized about as much where a cupola is not fluxed as where it is. The action of the blast causes the silicon to be oxidized or burned, somewhat as the oxygen of the cold air when blown into a steel converter attacks the silicon in steel. If this silicon is not carried off in slag from the cupola or blown out of the stack, it will be found as dross in the cupola's droppings or sticking

to the linings. Silicon in the iron is silica in slag, and for every pound of silicon reduced from the iron about two pounds of silica are obtained to be carried off as gas, slag or dross.

Softening iron by slagging a cupola is accomplished by reason of the fact that fluxing will reduce sulphur. The absorption of sulphur by iron affects it more than any change in silicon or other metalloid in the general remelting of iron. Hence the advisability of fluxing a cupola and melting hot is very apparent as an aid to obtain soft castings. For short heats, fluxing is generally omitted, but as an aid to promote long heats fluxing and slagging out are generally a necessity, no matter what change this may cause in the iron produced. Long heats or fluxing a cupola are not qualities to cause a founder to obtain undesirable results, for with the knowledge which he should possess of the changes fluxing and remelting of iron cause in the product obtained, he can by having lower sulphur or higher silicon in the iron charged counteract or allow for any change the action of remelting can produce. This is one of the reasons why the author attaches more value to noting the silicon and sulphur in iron than the phosphorus or manganese in regulating and making mixtures, as the latter two metalloids are not so radically affected or changed as the two former, in making and remelting iron. For a special treatise on this subject, see Chapter XXXI.

The weight of slag produced is dependent upon the character of the ore, fuel and flux used. A furnace can produce a greater weight of slag than iron, but, as a rule, 1,000 to 1,600 pounds of slag are made to the ton of iron. The richer the ore, the less slag in the

normal working of the furnace. The slag being constantly created at a furnace must be disposed of. We find machinery being utilized in this work, as in other manipulations of furnace practice. Some have it conveyed into large receptacles, which are then hauled by power to cars or some dumping ground. When overturned, they release the slag in a molten form, or solidified state, but the general plan used is to let it run from the spout Y, Fig. 10, page 94, to furrows in the ground, which may run for a length of two or three hundred feet, often covering an acre of ground. This slag is pulled out of its furrows with hooks in the hands of men before it has thoroughly solidified. In removing the same from the ground it is shoveled into carts and teamed to the dump, or may be thrown on cars to be transported and used for railroad ballast, or it may be used for making roadways. Slag is said to be also used in the construction of bricks for paving and building purposes, but with what success the writer has no information.

Making mineral wool from slag is a new industry lately started by remelting furnace slag in a cupola, under patents obtained by Wood Bros., of Wheatland, Pa. The process consists of charging the slag in connection with coke on the plan of melting iron. As the slag flows out it is met at the outlet of the slag-hole, in dropping, by three flat streams of steam, which divide its particles into threads of mineral wool and blow the same into a large wooden structure about 100 feet long and 30 feet wide, prepared for its reception. Variations in the character of slag create different grades of wool, which is sorted and packed according

to its commercial value. The wool may often be of such a coarse, poor quality as to be unfit for commercial purposes. There is always a difference in the density of the wool at every cast. The lightest is deposited or blown farthest from the cupola and the heaviest grade nearest to the cupola. The wool is chiefly used as a non-fire conductor packed between the wall and floor spaces of fire-proof buildings, etc. This mineral wool resembles in character that which the founder ofttimes finds coming from cupolas which are "slagged out."

Slagging out a cupola is an operation which requires more frequent taps than in a furnace. This is chiefly due to the difference in space each contains in their hearths for the collection of slag. Again, a foundry cupola has generally but a few inches between the slag-hole and the tuyeres, so that should the slag rise above the slag-hole, it would be very apt to soon approach a level of the tuyeres to "bung" them up. With a furnace the space between the slag-hole and the tuyeres is often six times that permitted in a cupola, and hence the less risk in "bunging up" a furnace's tuyeres with the slag. For every tap of iron made in a furnace, there are generally two taps for slag. This is termed "flushing a furnace." In the furnace shown, Fig. 6, page 71, the number of taps for iron during twenty-four hours generally ranges from four to five. In about the middle of every tap the furnace is "flushed" and then again just before tapping for iron.

The old way of tapping to flush a furnace, yet followed by a few, is simply by having a hole in the lining through to the inside of the furnace, and after the

same is tapped to plug it with clay, on the same principle generally followed in tapping a slag-hole in cupola work. The modern plan for making and operating a flushing-hole is that shown in Figs. 10 and 11, pages 94 and 97. At N is a bronze casting into which is inserted what is termed a "monkey tuyere," P, both of which are kept cool by a flow of water passing through them. In tapping such a slag-hole to flush a furnace the projection H is slightly jarred by means of a sledge which loosens the stopper R. After this has been removed, as shown by A, Fig. 10, a steel pointed bar is then used to cut through the inch or two of chilled slag, which has generally been formed in front of the plug F. This chilled slag is generally removed with ease, permitting the cinder to flow out. The time generally taken for the slag to be all flushed out ranges from five to seven minutes. It is not long after the slag has commenced to run before the blast makes its appearance, blowing gas and sparks of cinder for two dozen or more feet away from the flushing-hole. As soon as the flushing is completed, the iron plug stopper R is quickly thrust into the hole, which at once chills the slag around it, to stop the leakage of blast. The stopper R is a wrought iron bar with a cast iron cone cast on the rod to form the plug as shown. The distinction between this method of tapping a flushing-hole and that of the old plan used simply lies in convenience and the use of clay being avoided. The iron and slag-holes of a furnace are sometimes lowered or raised from their original position by reason of a furnace filling up with chilled iron, but if this can be avoided by tapping the iron, as well as the cinders, out of the slag-holes, as described in

the middle of the chapter, it is often done in preference to changing the position of the iron and slag-hole, as above described. Any one desiring more information on "fluxing" or "slagging" in its relation to cupola work is referred to Chapter XLVI. of this work and to the "Moulder's Text-Book," page 310.

CHAPTER VIII.

BLAST FURNACE vs. CUPOLA PRACTICE.

TAPPING-OUT AND STOPPING-UP FURNACES AND CUPOLAS.

It has taken much time, study and experience to attain the present perfection in controlling the output of a modern furnace. The history of furnaces could show many disasters in "breakouts," "boils" and explosions. When all is working well about a furnace everything seems very simple and as if taking care of itself, but it is when all does not go well that one is impressed with the fact that furnacing is often more like hades let loose than a paradise of comfort, ease and pleasure. An observing founder standing at a distance watching a furnace being tapped would often be at a loss to understand why a cupola cannot have its "breast" stopped the same as the "notch" of a furnace. The founder often has trouble with cupola tap-holes, which when once started to work badly will often continue to do so throughout the balance of the heat. The secret of the furnaceman being able to stop a notch by hand in the way it is generally done, is that the metal, when all is working well, is left lower than the notch-hole, about as illustrated at the level O, Fig. 10, page 94. How the metal goes down to such a low level as shown is a puzzle to the founder who has

never seen a furnace. The tapping-hole K is generally made at an angle somewhat as shown. After the metal has run out all it will by force of gravity, the blast pressure is increased above the ordinary to drive or siphon it out, as called by some, to about the level shown at the dotted line O.

FIG. 10.

With the weight of stock bearing down on the molten mass in a crucible and blast pressure of 10 pounds or more to the square inch, it seems reasonable to expect the results described. We know the weight of stock and pressure of blast exerts such a driving-out influence, from the fact that when about two-thirds of the pig beds are poured, the will metal often almost stop running, at which point the blast pressure being increased a fourth more metal will often be forced out, and the more acute the angle of the notch, so as to carry its opening lower into the crucible, the more metal to a depth of about 15 inches below the level of the bottom of the iron trough can be siphoned out in tapping a furnace. A question to suggest itself at this point is the reason for having such a body of metal below the level of a notch-hole. The great depth sometimes attained is not really desired, but is caused by the liquid mass burning out the bottom brick-work.

When "blowing-in" a new furnace, the bottom bed of

the hearth or crucible is not much over four inches below the level of the notch, but continual running and "fast driving" of a furnace soon cut out the bottom lining, so that it is no uncommon result for metal to burn the bottom down three to four feet below the level of a notch, as indicated by the dotted line S, in Fig. 10. Furnacemen claim it is not until a bottom is cut down for a foot or two that the best output and quality of product can be obtained, and also that a deep bed is very desirable to help maintain a uniform product. Often has a furnace cut the bottom out to such a depth as to force an opening for metal to pass downward through the ground or outward through the sides, something as indicated by the lines N M and H, Fig. 10. The havoc such an escaping body of metal can make, if bursting out, as it often does, into a reservoir of water, which is always more or less deep around the hearth of a furnace at N, can be but partly conceived.

The mass of liquid metal in the bed of a furnace may often weigh 50 to 100 tons. This often solidifies and lies in a furnace until it may be torn down, or the hearth portion removed to permit breaking up by dynamite. It has happened that, through a furnace "getting off" or working badly, the bed of metal has solidified above the level of the notch, so that to tap the metal out of the furnace it would have to be drawn off at the flushing or slag-hole at A, Fig. 10. Some furnaces have run for a week or two in this manner before they were able to get the solidified mass melted down, so as to again draw metal from the notch-hole. A furnace in this condition must be tapped much oftener than when it can be tapped at the regular notch. It is often surprising how rapidly,

through a furnace getting cold, the bed of metal in the hearth will solidify, and then again how, when a furnace is working hot, it will often cut out such a solid mass of iron, but generally, like all workings of mechanical affairs, the evil is prolonged more than the good is hastened, when trouble once begins.

Fig. 11 shows some effect of a chill in a furnace causing metal to solidify around and above the notch. This is one form taken, and another may be, instead of having a chill all around the sides with liquid metal in the middle, to have but one side solidify while its opposite is in a fluid state. Solidification of such masses generally occurs by reason of scaffolding, cooling off the furnace, and then letting a mass of chilled stock slip down to the tuyeres, or lower into the hearth. There are two forms of such evils resulting from a slip, the first being the solidification of metal as above described, and the other what is called a "lime-set," which is generally caused by reason of a furnace carrying a heavy burden of limestone, and the furnace becoming cold from "scaffolding," or any other bad working, chills the lime so that it becomes too thick to flush out, and "sets" in a solid state in the crucible or at the tuyeres.

Furnacemen generally fear a "lime set" more than that of molten metal solidifying, for the latter can be melted away much more readily than the former. Lime sets have been so serious that furnaces have had to "blow-out" to remove them. A method sometimes employed to gain access through solidified iron, which might close up tuyeres, or a "notch," so as to prevent its being tapped, is that illustrated by the hydrogen blow-pipe at A, Fig. 11, page 97. As used in this case,

FIG. 11.

it is simply a 2-inch gas pipe leading from the hot blast pipe (cold blast can also be used), into which a ¼-inch pipe D carries a stream of coal oil. This is contained in a can sufficiently high to force the oil out and overcome the blast pressure at the outlet, there to ignite by combination of the air and oil. Sufficient heat is thus generated to melt the iron or enable it to be knocked away. Space is in this manner made to admit of the blast and metal blowing out to farther cut away the solid iron to a point warranting the replacing of the notch for regular working. In some cases a coke or coal fire will be encased in front of the blow pipe, and the stock is to be cut away as illustrated by the small lumps of fuel seen at E, Fig. 11. The principle involved in this process is one which may be often practically applied by the founder in preparing a casting to be burned, by bringing the point of fracture to almost a molten state, thereby saving labor of melting and handling a large quantity of molten metal. It also may at times be found of value in assisting to cut away heavy bodies of iron that might be found almost impossible to be otherwise manipulated. In using this device to cut out a notch of a furnace, great care is exercised, as it may cut through the chilled material and, without warning, the molten contents may burst out with such a force as

to empty the furnace in a few minutes. Men have been struck by such outbursts and almost buried alive in a pool of metal before assistance could be rendered.

The process for hand-tapping, when all is working well with a notch of a furnace, is first to take an iron bar and prick into the stopping clay, starting a hole as seen at the entrance K, Fig. 10, the "keeper" being careful to give it the shape and angle desired. As the clay is loosened, a ⅜-inch rod, having a flat lifter about 1½ inches square on its end, as seen in Fig. 13, below, is used to pull the loose clay up out of the hole, which is generally made about 4 inches in diameter at the top, tapering down to 2½ inches at the bottom. Picking by hand bars and lifting out the loosened clay is continued until the solid clay shows by its red heat that its thickness preventing the metal bursting out is not over 3 inches; then a steel bar of about 1¼ inches diameter having a sharp point is placed as shown in Fig. 10, the upper end resting on a piece of pig metal thrown across the top of the iron trough, as seen at T. A sledge is now used at the end F, the bar in the meantime having its point guided by hand so as to cut around the edge of the hole. This is continued until metal is seen to commence oozing out, when the bar is driven through the started body of the clay into the metal seeking to force itself out. The bar is then

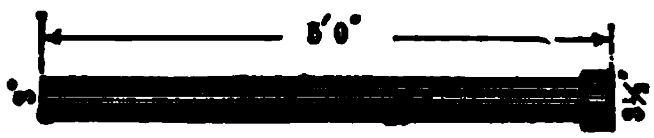


FIG. 12.

FIG. 13.

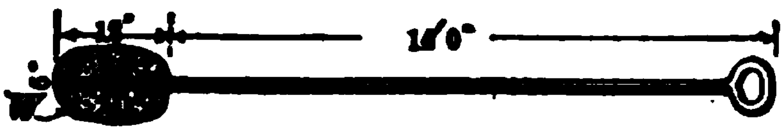


FIG. 14.

pulled out, in which movement, should any difficulty be experienced, a device as seen at P, Fig. 10, is used, which by sledging on the end of the wedge shown, backs the bar out of the notch. Sometimes, instead of the affair shown, a stout ring will be used, and by inserting the wedge as shown a similar result is insured. This device is a simple affair, and would suggest to many founders a remedy for difficulty often experienced in pulling back bars driven into the breast, tuyeres or slag-holes of a cupola.

After a bar has been removed from the notch, the metal generally flows out with a fair speed, but should lumps of dross or fuel impede its passage, a smaller bar than the one used to tap it is generally inserted in the notch-hole, and by working it up and down the passage is eventually cleared so as to permit the flow desired. It is not infrequent that the metal rushes out with too great speed, often doing so with an unexpected burst, so as to strike the "keeper" with a spreading sheet of rushing metal if he is not continually on his guard. After a furnace has been tapped and the iron commences to flow well, a cover composed of fire brick held in an arch shape by a cast iron bracket casting is swung by means of an iron arm close up to the furnace front at the cooler V, Fig. 10, and let rest on the edge of the trough shown. Any space between this cover and the furnace shell is closed by means of sand being thrown around this section. This cover prevents the metal and slag from blowing up against the shell of the furnace to burn it out.

An arrangement which is generally used at every hand-tap to assist in lessening the force of the stream is a stopper, as seen in Fig. 14. The end W, being

held at the mouth of the notch, can, if there is not too great a force, often almost stop the escape of metal. This stopper is made by rolling a 1¼-inch rod in a stream of slag as the furnace is being flushed out. Should the metal force itself out too fast at any time during a tap, the blast is slackened or stopped, until the metal has flowed off all it will of its own gravity, when the blast is again put on, and the increased pressure then drives out the metal and slag as above described. This end achieved, the blast is then completely shut off to stop the notch.

The process of stopping the notch by hand is proceeded with as rapidly as possible, in order to prevent loss of time in making iron. The first thing done is to throw a sheet-iron plate across the top of the iron trough; which, covered over with sand, protects the men from the heat of the trough, and permits them to come directly over their work. The notch at this stage greatly resembles a crater that has died down from vomiting its lava. Lumps of dross and fuel will be found sticking to its sides, which have been greatly increased in area from the effects of the "blow." A bar is used to loosen this *débris*, and then an iron scoop pulls it out of the notch-hole. After this *débris* has been removed as well as the inflowing slag will permit, the bar is again used to push down into the crucible any lumps which might be sticking to the sides of the notch, and a bar of the same shape as Fig. 13, only made of round iron, is now used to press down into the crucible the dross and slag which endeavor to rise to fill the notch-hole. This done, the bar is hastily removed, and men standing with two shovelfuls of clay toss it into the notch-hole, the clay is then quickly

rammed downward as far as possible with the rammer rod just described. After as much clay is pressed downward with these rammers as is found possible, then a round stick about 3 inches in diameter at the small end and 3½ inches at the top, having a ring to prevent the sledging splitting the timber as seen at Fig. 12, is inserted into the notch and driven with two sledges down to the bottom, thus driving the dross and clay back into the crucible, as far as possible, to make a solid filling of clay in the notch at its bottom. This method of packing having been performed half way up the notch, the packing stick is removed, the blast started and the balance of the notch is then filled with clay packed with hand rammers. A stream of hot blast is now turned on the top of the notch and the clay grouting used to coat the iron trough, so that at the next tap there will be no dampness to start a "boil."

The above can be called one plan of hand-stopping a furnace, but of late a machine has been designed to be worked by steam forcing out a stopper,* by which a furnace can be stopped at any part of a tap without shutting off the blast.

Many furnaces are now using stopping machines. They prove valuable in many ways, especially in permitting a steady blast, as cited above, which gives a greater output and more uniform grade of metal and greatly lessens the chances for "scaffolding," due to a steady heat being maintained in the furnace. It is said that all users of these stopping machines prize them very highly, and it now looks as if it would not be long before all furnaces would adopt them in their

* Patented by S. W. Vaughn, Johnstown, Pa.

practice, especially those using fine grades of ores, as any stoppage of blast is apt to cause a temporary chill and to retard good working of the furnace.

It is not every kind of clay that will answer for stopping a notch. It must be of a quality to withstand fire to the best possible degree. Some use a good grade of fire clay; others will grind up old crucibles to mix with the fire clay in an effort to improve its heat-resisting qualities. The clay is mixed to a consistency about like that found good for cupola stopping clay, and in some places is prepared in pans crushed by heavy rollers.

The success of stopping a notch by hand being due to the fact of having the metal lower than the level of the notch, affords the furnace an advantage not permitted to the cupola. Conditions in the latter calling for a "bottom drop," every heat makes it most desirable that no metal should remain in the bottom of a cupola when a heat is finished. For this reason a bed of a cupola as seen at Y, Fig. 15, is generally made on a slant, and the tap-hole placed at its lowest level, as seen at R. With such an arrangement, when difficulty in tapping and stopping once commences, it often causes the cupola tender much harassing labor, and the founder loss in casting. Some furnacemen might suggest placing a tap-hole on an angle somewhat after the line seen at G, and then at the end of the heat breaking a way into the bottom to give a hole on a level the same as R, both seen in Fig. 15, in order to drain the cupola so that no iron will be lost or spattered at the "bottom drop."

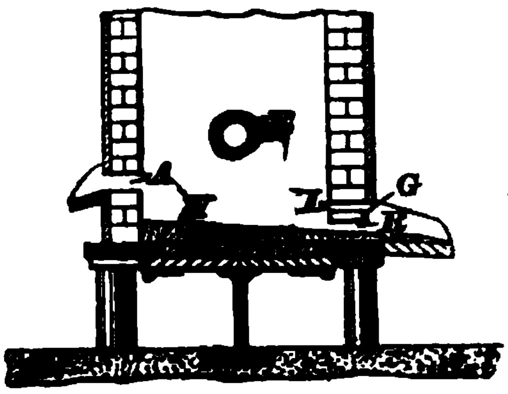


FIG. 15.

Tap-holes in foundry cupolas generally require opening and stopping at intervals, often not five minutes apart; and, again, a tap-hole has often to be stopped when there is a considerable head of iron in the cupola above the top of the tapping-hole. To do this successfully is often a feat deserving praise. There is one way a founder can often, in cases where it is difficult to obtain a good, clean-working tap-hole, secure one which will work satisfactorily, and that is by raising the tap-hole above the bottom, as illustrated by the hole I, seen above R in Fig. 15. The way to do this, when a cupola's breast is causing trouble, is to dig out the breast clean to the fuel, then stop the blast and quickly pull away any droppings of metal or slag which might be dripping over the bottom, and press down clay an inch or two thick all over its surface. On this then set a plug to form the tap-hole, after which the breast is quickly rammed in shape after the usual practice. This method raises a tap-hole above the level of the fluid metal and provides an inch or two-inch space for it to rise in before the level of the tap-hole is reached; then, before dropping the bottom, dig down to the bed's level, as above described. In some cases the metal not dropping very fast or slag making its appearance after the blast has been shut off, it may be practical to form a good, new breast on the old bed; but in either case, where trouble is experienced with a bad breast, it is generally advisable to stop working with it, dig out the old breast, shut off the blast and form a new breast as quickly as possible, for a tap-hole that will give trouble for a half hour often continues to do so until the end of the heat.

The author recently saw a wrinkle used by the Ohio

Steel Co., Youngstown, O., for lessening labor in tapping their cupola, which would often work well in foundries where large bodies of iron have to be accumulated before tapping. This was simply to lead a rubber hose from the wind belt or a tuyere with a $\frac{3}{4}$-inch piece of gas-pipe about two feet long at the loose end, to blow cold blast against the stopping as soon as the hole was plugged. By aid of this, they were enabled to use a very small quantity of clay in stopping up the tap-hole, which made the task of tapping very easy.

CHAPTER IX.

MODERN FURNACE vs. CUPOLA PRACTICE.

MOULDING AND CASTING OF SAND AND SANDLESS PIG IRON AND "OPEN SAND" WORK.

The many wrinkles which are employed by furnacemen in controlling the distribution of 20 to 100 tons of molten metal, when tapped, display experience and knowledge which the foundry manager and moulder can often well utilize in founding. Every branch of handling molten metal has its own little "tricks" in practice, which have often taken years to perfect, and I propose to now illustrate some of those involved in controlling metal and making "open sand" moulds and casts at a blast furnace, as the information and ideas such study imparts, even though furnaces should abandon casting pigs in sand beds, as referred to on pages 114 and 116, will prove of value in many ways to general founding.

A moulder, however well experienced, who has never seen a blast furnace, would be very liable to make a nice mess of things at the start, should he attempt without any instruction to direct the making and casting off of a floor of pigs. In preparing a moulding bed for making pigs, the floor is dug out

from 3 to 4 feet deep, and then filled up with a medium grade of bank sand, of a very open, sandy nature. The reasons for going down to such a depth to simply mold a few pigs that are not over four inches deep, also for using such a coarse grade of sand having very little binding qualities about it, are found in the desirability of having conditions as favorable as possible for permitting the escape of steam from any excess of moisture or water, which the sand may contain, or for draining downward, and hence lessening the chances of a "boil." The moulder must bear in mind that when once a stream of iron is started, the furnaceman cannot plug up a "run-out" or dampen the ardor of a little "kick," the same as when pouring a mould, and hence the precaution not to be dependent upon judgment in getting sand just the right "temper," etc. Where sand is as open as is generally used for pig beds, and as deep in the floor as above described, water, after having been absorbed to a certain point, will, to a large degree, filter through coarse sand towards the bottom of its depth, so that should an excess of water have been used, the chances are it will not cause the "boil" it would certainly do if the sand were of a character like that generally used for green sand molding in a foundry. Another point which makes it desirable to use such open-grained sand is that of saving labor in mixing sands. About all the mixing that furnace sand generally gets is what the force of water from a two-inch nozzle gives it. I have seen such a stream play steadily on one spot for two or three minutes and no attention paid to it. If moulding sand in a foundry received such abuse, the iron would mostly go to the roof the moment it struck

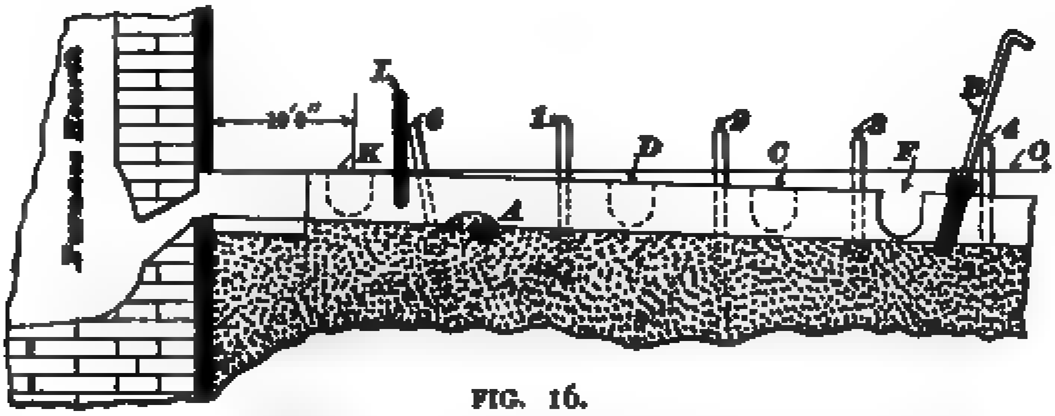


FIG. 16.

the sand. But like all else in mechanics, there is a limit to abuse, and too much carelessness in wetting down the floor of a casting house can result in disastrous "boils."

Moulding pigs is generally performed by three men, who will mould up fifteen to twenty beds in about one hour. The main runner leading to the pigs Nos. 1, 2, 3, 4, 5, 6 and 7, Fig. 21, page 109, is called the "sow runner." There are generally from 24 to 28 pigs to a sow. Each sow is leveled, likewise the pigs connected to it, but each bed is, in commencing from the lower end, made

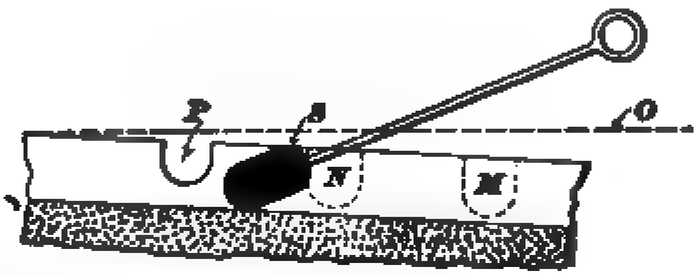


FIG. 17.

FIG. 18.

FIG. 19.

one or two inches higher as they approach the last bed, so as to conform closely to the incline of the main or "iron runner," as it is generally called, which has a fall of about eighteen inches in one hundred feet. Any more fall than this would generally cause the iron to flow with too great a rush, and should it get away from the furnace any faster than usual, the chances are it could not be controlled, and instead of its being distributed as desired throughout all the pig beds, the lower two or three beds would be overflowed, and a "boil" easily started by reason of a large area of floor space being all covered with a plate of fluid metal, permitting no escape of gas and steam from the sand cores between the pigs. The founder often receives pigs united together, and often much thicker in depth than usual. These are called "jump cores," and are so formed by reason of the body of sand in the mold separating the pigs being raised or pressed to one side by the action of too quick a flow, poor sand, or a little "boil." It has been no uncommon occurrence for metal to come so fast down the iron runner that it could not be controlled, and by reason of covering over a large area, cause a whole tap to go under the drop, or, worse still, require dynamite to break it up sufficiently small to be charged into the furnace, along with the ore, or sold for scrap metal to be re-melted in air furnaces or big cupolas.

The making of the iron runner is generally the work of the "keeper." Figs. 16, 17, 19 and 20 show different views of such runners, and Fig. 26, page 110, a perspective view of the whole.

After a furnace has been tapped, the metal often comes slowly. To prevent it from chilling until its

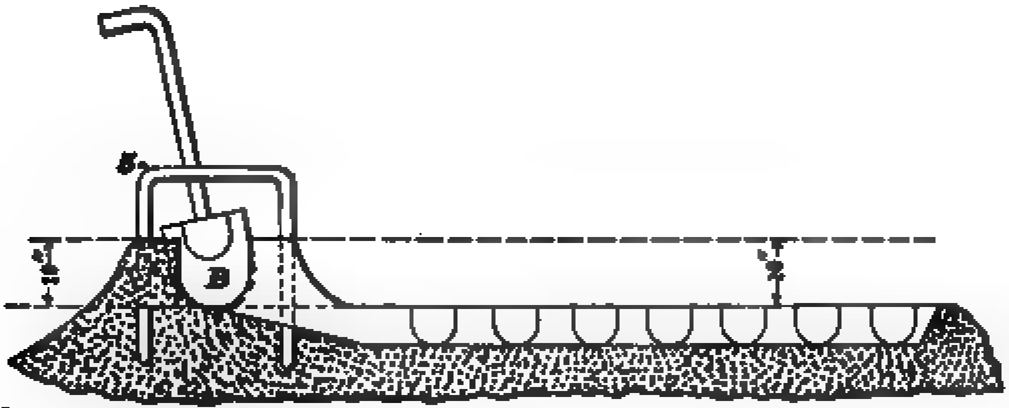


FIG. 20.

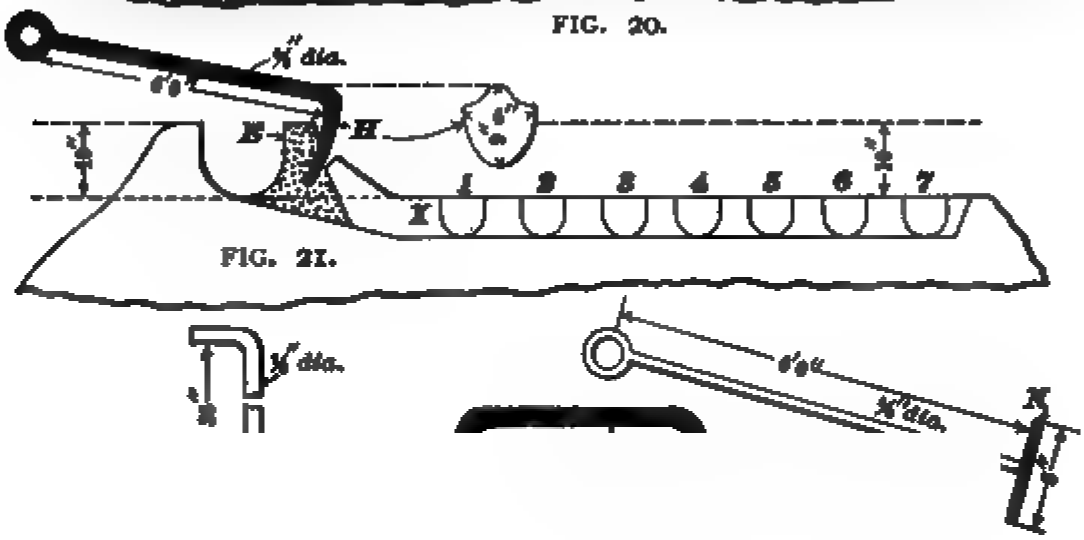


FIG. 21.

speed is sufficient to fill the runner as desirable, a little knoll, as at A, Fig 16, is generally formed in the "iron runner," as shown. This causes sufficient body of metal to be collected to keep itself fluid until the flow is increased enough to overflow the knoll, by which time the chances are the flow will have enlarged itself to the degree of sending a fair stream

FIG. 26.—PERSPECTIVE VIEW OF A CASTING HOUSE.

down the iron runner. The iron in first flowing down the runner carries more or less slush of iron and dirt in the front of its stream. This will often pile up so as to require to be broken by means of a wooden pole in the hands of a man, as seen in Fig. 26. As soon as the metal has reached and filled the lower bed, a "cut-

ter," as shown at Fig. 22, and in the hands of the man at the left in Fig. 26, is then quickly placed with pressure so as to be bedded into the main runner, as seen at B, Fig. 16. A few moments before this is done a man with a ravel, as seen at Fig. 26, pulls away the mound of sand, closing the connection from the "iron runner" to the "sow," as seen at C and D, Fig. 16, also at E, Fig. 21, to make an opening, as seen at F, Fig. 16. The top level of the pig beds should be below the level of the bottom of the main runner in order that all the metal may drain itself out of the main runner; and, again, the pig beds should not be too far below the level of the bottom of the main runner, as this would cause the metal to rush from the main runner to the sow with a force very liable to cut up the sand where the metal would strike the bottom level, or wash away the cores between the pigs. The distance sought for is about that shown in the cuts, Figs. 20 and 21. If the moulder would consider trying to make a mould with what is generally termed a medium grade of bank sand, having the life pretty well burned out of it, he will then be in a position to understand how easily a rush of metal could cut up a pig bed of moulds, and the necessity for having certain conditions prevail, even if it is only "pigs" that are being moulded and cast. As the metal flows down the runner, much of the sand floats with the iron; but as pigs are not finished or condemned, if they are a little rough on their surface from dross or sand, there are no serious objections as long as it is not sufficient to impede its passage to the pigs. At H, Fig. 21, is seen the "ravel" as it is placed in the sand ready to make an opening to admit

the molten metal from the main runner to the sow.

At Fig. 23 are shown what are called "runner staples," which are used to support the "cutters," as seen at Nos. 1, 2, 3, 4, 5 and 6, Figs. 16 and 20, also in the perspective view of the main runner seen in Fig. 26. As each pig bed fills up, the cutters stop the flow of metal, admitting it to flow into the adjoining bed as above described. When half of the beds are about poured off, slag then commences to come out with the iron at the notch-hole. To prevent the slag from passing down the runner to the pig beds, a "skimmer plate," seen at I, Fig. 16, is knocked down to about the depth shown and then some sand is thrown against it on the side at K. By ramming this sand, the opening below the lower edge of the skimmer plate I and the bottom of the runner can be decreased at will, so that only iron may pass beyond the skimmer plate and its flow may be regulated. The slag is let run out at the "slag runner" shown at the dotted lines K, Fig. 16. The slag running out at the tap-hole at every cast is considerable; often for every ten tons of iron there may be two tons of slag.

After the pigs are cast they must be broken. This constitutes the most laborious work about a furnace. Before starting to break the pigs, which is not done until they have solidified sufficiently to not "bleed," sand to a depth of about ¼ inch is thrown over their surface. Two or three men wearing wooden soles about 1½ inches thick attached to their shoes, now start at the first poured bed with pointed 1¼-inch bars about six feet long. By inserting the point of the bar between the pigs at the end furthest from the "sow," they are readily broken loose from the

sow. After the pigs are all separated, the sow is then broken by taking the ends of the pigs of the next row as a rest to pry the sow up; if not broken from being lifted, a sledge is then used. When two to three men will separate about five hundred pigs and break about eighteen sows in several pieces in about a half-hour's time and not seem in any hurry, it is safe to conclude the work is down to a very commendable system.

After the pigs and sows are broken as above described, a stream of water is turned on to cool them off so that they can be handled and removed from the casting house in time to permit the bed to be re-moulded for its next turn in casting. This, in a furnace of the size seen on page 71, making five taps every 24 hours, leaves but about four hours for the "iron carriers" to break up and load on buggies for removal from a casting house about 40 tons of pig metal. To admit of a buggy being brought close to the iron to be loaded, a wooden track fastened together in sections of about 10 feet long is laid down on the casting floor to any length or turn desired.

There are always two floors to a casting house, so as to permit one being molded and got ready for a casting while the other is being relieved of its pig metal and wet down ready for molding. There has of late been a patent taken out for a device which will pick up all the pigs with the sow and run them bodily on a traveling crane out of a casting house to a machine which will break the pigs in two pieces, as well as the sow to any length desired, but for some reason furnaces do not seem in a hurry to adopt it.

An apparatus for casting and handling pig metal

has recently been designed by H. R. Geer, of Johnstown, Pa. It provides a rotating pig bed, receiving the molten metal from the furnace, casts and cools it in separate pigs and delivers the cool pigs on cars or at any other desired place of deposit. This is a very novel device, and where pigs cast in "chills" are acceptable and a hold-back skimmer or some other plan is adopted to control the flow of iron in order to maintain any desired speed in the rotating, moving platform of pig moulds, the method is practical.*

Another device embodying a similar principle was patented by E. A. Uehling, of Birmingham, Ala., patent No. 548,146, granted October 15, 1895. Mr. Uehling proposes to first catch the furnace metal in standing ladles and then turn the metal from these into the pig moulds to whatever speed the movable table may demand. The author has been informed that the Sloss Iron & Steel Co., of Birmingham, Ala., intend to give this apparatus a practical test. If the principle involved in the above apparatus proves successful, it will, in all cases where chilled pigs are acceptable, do away with the labor involved in moulding pig beds, breaking the iron after it is cast and carrying the same out of the "casting house," a saving which is of no inconsiderable concern in the manufacture of pig metal. The Lucy Furnace, of Pittsburg, Pa., has for the past five months been using a similar device, which is working well and is said to make a saving of ten cents a ton on all iron made.

As a labor-saving device, casting pigs in "chills," or an iron mould bedded in the floor, is sometimes prac-

* This device was fully illustrated in the *Iron Trade Review* of August 6, 1896.

ticed, but I only know of two furnaces using them at the present time in the United States. Some raise objections to floor iron moulds for casting pigs in. The first is that of the chill such moulds impart to pig metal. But to this evil there is not the objection to be raised at the present day when iron is sold on chemical analysis, as when it was judged wholly by its fracture or the grain which the iron presented, as chilling an iron is not known to make its chemical composition any different when re-melted except in one respect, and that is in sometimes causing pig iron to be slightly higher in sulphur than if it were cast in sand, owing to furnace metal permitting sulphur to escape when long in a fluid state, a factor largely proven by the fact that the top half of a pig will often contain more sulphur than the bottom portion, or that part cast down. Catching the metal in ladles before pouring it into pig moulds, as referred to above, would largely overcome the objection just cited against chill moulds giving higher sulphur in the pigs, as it is generally conceded that the longer the metal can be held liquid in large bodies the greater the chance for sulphur to escape.

The second objection to floor iron moulds lies in their liability to crack or warp from the application of the water used to cool the pigs off so that they may be carried away in season to prepare the floor iron moulds for their next cast. This labor is about equal to moulding the pigs in sand, as the iron moulds generally require to be grouted or washed over with a coat of thick clay wash. Since the furnaces have adopted the wrinkle of using coarse grades of sand and making their floors deep so that water will readily pass from the surface to the

bottom, without leaving the sand to be used for moulding as so much mud, the stationary "iron mold," bedded in the floor of the casting house, has practically little to recommend its adoption.

"Chill pigs" have at least one point greatly in their favor, and that is, that they are free of scale and sand (silica), the effect of which is to increase dross or slag in a cupola. The greater the quantity, the greater amount of flux and fuel necessary. It also retards the speed of melting, as well as decreasing the melting capacity of a cupola, and causing "dirty iron" to be poured from the ladles. To assist in lessening these objections, many founders go so far as to "tumble" all their "gates," etc. Could such shops also secure their pig metal free of sand, they would more than double the benefits to be derived from having clean iron to melt and pour into their castings. Knowing the value of possessing "clean iron" to melt in cupolas, and also what pigs free of sand mean to the basic open-hearth process, the author is led to believe that the adoption of chill pig casting, after the plan advanced by Messrs. Uehling and Geer, and in use by the Lucy Furnace, will be rapid; and the day is not far distant when a majority of blast furnaces will be using such methods.

A perspective view of a casting house, as it generally appears about one-half hour before casting time, is seen in Fig. 26. The keeper seen standing by the notch of the furnace has got his runner all made with the runner staples and cutters placed in position. The man on the right at the lower end of the runner is shown just finishing ramming the last bed of pigs. To afford an idea of casting, the first man on the left of

the main runner is shown standing ready to drive the cutter into the runner to stop the metal from flowing to the first bed. The second man seen on the left stands ready to ravel out the branch runner to the pig bed. The third man having a pole in his hand is supposed to be breaking up the crust of slush formed in the front of the metal as it first comes down the main runner. These three last men are simply placed in position shown to illustrate their work if the metal had been actually running down the runner as above described. To those never having seen a casting house, Fig. 26 should give a general idea of the methods employed for moulding and casting pig metal.

Moulders are often employed at a furnace to make moulds, open and closed, to be poured with metal as it comes down the main runner. To regulate the flow so as to stop it as soon as the mould is filled is a trick often worth knowing for application even in a foundry. At Fig. 18 is seen a section, through A B of Fig. 19. The moulds shown are supposed to be "open sand" plates, which are wanted as uniform in thickness as possible. By the plan shown, if the metal is as "hot" as is generally obtained, the plates can be made to not vary over ⅛ inch in thickness, which is as close as a founder can generally run them where he has metal in a ladle supposed to be under perfect control. In explaining this wrinkle, attention is first called to Fig. 17, which is a section of the main runner. At the dotted lines N and M is seen the depth to which the branch runners connecting the sow and main runner are generally made and which are supposed to drain all the metal from the main runner until "cut off" by the "cutters" B, as seen in Figs. 16 and

20. By making a comparison in the depth of the opening P with M and N, Fig. 17, it will be seen that the opening at P could not deliver any metal unless the iron was raised in the runner to its level, and the chances are in the general working that the iron in the main runner might never reach the bottom of the opening at P. But to compel it to do so, a stopper composed of slag chilled on the end of a one-inch iron rod, as seen at S, Figs. 17 and 19, is placed in the main runner to impede the flow of the metal. This action raises the height of the metal in the runner so as to make it flow out at P, and the moment the stopper S is lifted, the metal is lowered below the level of this outlet, and hence instantly ceases to flow into any mould which may be run by such a plan. This last wrinkle well governs the actions of the main runner in filling moulds; but there is still another point to guard against where two or more castings are poured from such a branch runner, and this is the tendency of one mould to fill before another, and hence furnish castings thicker or thinner than might be desired. To regulate this point, a portion of the edge of the mould is cut away to the thickness desired, as seen at B in the plan view, Fig. 19, and also in the section A B, Fig. 18. Such moulds being generally raised above the level of the floor, it can be readily conceived that any overflow at the points B will be received at a lower level than that of the castings, hence the difficulty with good metal of obtaining such castings thicker than they might be desired. It may be well to state that outlets, such as at P, should be made well up towards the upper end of the main runner, so that when the stopper S is lifted, the metal will then have a chance to

run on down the runner to fill the pig beds through lower outlets, as at N and M. The dotted lines O O, in Figs. 16 and 17, are supposed to be level, and the angle of the main runner shows the incline from this level line.

A plan of the pattern is seen at T, Fig. 25. The recess at A is to assist the pigs being broken in two pieces when cold, and the formation as seen at B where the pig and sow join, in making their separation at this point easy when breaking the iron after a cast. The same number of patterns is used as there are pigs to be moulded in a bed. A good method of forming these patterns is by a combination of sheet steel and wood. The steel which forms the outside, as shown by the heavy black line at P, is about $\frac{3}{32}$ inch thick, and formed to shape over an iron block before the wood is secured, as shown at V V and at S, the latter being a 1¼-inch piece of hard wood, secured by wood screws passing through the steel at the upper edge every 4 inches into the wooden board. To secure the pattern at its end, a ¼-inch rod passes clear through each end and is riveted. This method makes a very light pattern, and one which will last for years, and discounts a dozen times over the old plan of making all-wooden patterns, which is still used by some. The principle involved in the construction of these patterns is one the founder and patternmaker might often well utilize. The sow pattern is made of a continuous stick of timber, having one side at T faced with a sheet of ⅛-inch steel, so as to retard warping of the pattern. There is also a piece of iron ½x2 inches set in and screwed down on the top surface of the sow pattern, as seen at K, for the purpose of leveling; as constant friction of a level on

the surface of wood would cause it to splinter and be uneven for leveling purposes.

In using these patterns and bedding them in the floor, there is no heavy sledge hammer used to settle them, as a moulder generally does with his patterns. In fact, no sledge or hammer is used on them, the only thing leveled is the sow; if one end is high, the pattern may be lifted and sand scraped away from under it, or the low end may be raised and sand tucked under it by means of the handle end of the shovel or a push of the foot. The sow having been leveled, the pig patterns are then laid down on the floor, which has previously been leveled off with a shovel as near as the eye can judge, and which is generally done truer than many of our moulders are capable of doing. When the patterns are all in place, sand "riddled through the shovel" fills up the space between them, and a man with a rammer 12 inches long, as seen at the right, in Figs. 26 and 24, rams the sand between the patterns. After going over with this rammer once, sand is then shoveled over the bed, and a flat scraper 18 inches long scrapes the sand off level with the top surface of the patterns, which is all the packing or sleeking the surface or joint of the bed receives. Sand having been pushed with the back of the scraper to raise a mound of sand between the pig beds to prevent metal flowing over, the sow pattern is now drawn out by means of the lifting iron seen at D, Fig. 25. The sow having been removed, the pig patterns are then drawn out by first raising one end with the hand in the recess at the end R until they can be lifted by the center, when they are tossed on to the next bed ready to be set up for another filling of sand. Some moulders might feel

like asking, "Was there no swab used?" No, the wetting the joint receives is as if by chance the fellow on the other side of the house wetting down the floor should, in turning himself carelessly, throw a stream of water over the joint. I do not wish to be understood as saying that because pigs can be made with such apparent carelessness, rapidity and little labor, the moulder should do the same in making "open sand" work in a foundry; but nevertheless the principles involved should be studied by those moulders who must have a whole day to make about a dozen cast "gaggers."

Modern moulding and casting of pig metal involve points which the founder can often utilize to advantage. The principle involved in using open grades of sand and having deep floors to afford a chance for excessive moisture or water to pass downward, is one the founder having much "open sand" work to do can often well adopt. How frequently do we find moulders making "open sand" work that will "kick" and "bubble" in such a manner that, when the castings come out, it is a question whether they came from a foundry or furnace "boil." Drop close grades of moulding sand and adopt a sharp open sand, and use regular moulding sand only where the metal from the pouring basin strikes the flat surface of the mould, and the trouble as above described with "open sand" work in a foundry will decrease.

CHAPTER X.

BLAST FURNACE vs. CUPOLA PRACTICE.

UTILITY OF DIRECT METAL FOR FOUNDING.

In the first days of founding, castings were made from metal taken directly from the furnace making the iron. The difficulty and uncertainty of obtaining the grade of iron desired and the fluidity necessary to insure an aid to good work, as well as the advantage of having metal when best suited to the founder's needs, gave rise to the origination of the cupola to remelt iron. Had the furnace advanced anywhere near the degree in assuring a uniformity of "grade" that it has in increasing its output, many more castings would be now made direct from furnace iron. While many may question the ability of the furnace to ever achieve any better results in always obtaining a uniformity of product, competition will strongly influence an effort for improvement in this direction. Aside from the above evil, is that of the trouble caused by the "kish" found with metal high in graphite, or high-grade irons. Often after a furnace "cast" of foundry or Bessemer will the floor of the house be covered with "kish," which in appearance resembles flakes of silver lead or plumbago, and is the same flaky carbon material so often found separating the grains of pig metal and castings. It can be removed

from fractures by means of a stiff brush or rubbing.

The evils to be expected from metal possessing much "kish" are mainly in "cold-shuts," spongy, porous spots in castings and a separation of the metal's grain at places where "kish" might be confined. One might as well try to make a union of oil and water as of "kish" and cast iron. Were it possible to collect or skim off all the "kish" in high grades of direct metal, little damage might be expected; but this is not practical, as the "kish" keeps rising to the surface as long as the metal is in a fairly fluid condition. Appliances have been invented with a view to collecting the "kish" in pouring runners, etc., before the metal would enter the moulds, but these have proven of little value. It may be said that metal possessing much "kish" is unfit for pouring castings.

Direct metal free of "kish" can make very good castings, and for some classes of work might often prove more desirable than cupola iron, as less sulphur can be obtained in direct metal than with iron re-melted. Iron cannot be re-melted in the cupola, with coke or coal, without increasing its sulphur from 10 to 100 points. The re-melting of pig metal entirely destroys the "kish" that appears with direct metal.

The life and fluidity of direct metal, compared to cupola iron, are qualities many will question. If a furnace is working properly, its product will compare very favorably, as regards these qualities, with cupola iron. The writer has seen hotter iron from a furnace than was possible to be obtained from a cupola and keep its life or fluidity exceptionally long. In fact, the author is of the opinion that direct metal can have such an initial heat imparted to it as to create a much greater

life to the fluidity of the metal that can be obtained in re-melted iron.

To utilize direct metal, some have thought it would be a good plan, in order to overcome the difficulty from "kish" and obtain a more uniform product, to first pour the metal coming from two or more furnaces into a large receiver or reservoir so arranged as to closely confine from 50 to 100 tons of iron, the idea being that if the metal should have "kish" in one furnace, another would be free of it to mix with it, and hence an average could be obtained which would be sufficiently free from "kish" to obviate any defects in the casting. The information which the writer has obtained as to the success of this plan is not very favorable. The difficulty found consists in the metal losing its fluidity and life too much by the extra handling and detention of the metal in the fluid state. Where work is very massive, not requiring good "hot iron," this reservoir method may be of much value; but the difference which exists in the cost of direct metal and cupola iron does not warrant any very great chances being taken in losing castings on account of the fluidity and uniformity of a "grade" not being as desired. With work that involves little risk, however, "direct metal" in these days of close margins may command attention in some cases.

It is no uncommon thing for us in our foundry to make small castings with direct metal carried by three men in a "bull ladle" taken from a furnace close by us. The plan which we adopt in obtaining such small bodies of metal is simply to catch the metal with a "hand ladle" by dipping the iron out of the main runner as it flows to the pigs and pouring it into a "bull

ladle." We have made very good small castings by such a plan. We have also taken "direct metal" in crane ladles by having a car run on a track, sunk sufficiently below the level of the main runner to receive the metal from a branch runner extending out beyond the casting house. With iron containing silicon below 1.50 and sulphur above .030, it is rare that any "kish" is seen, and when such direct metal can be obtained very good castings can be secured. Of course, with such low silicon and high sulphur iron it is not to be expected that any work below one inch in thickness, requiring any great finishing, can be satisfactorily obtained, but for bodies above one inch in thickness, very little trouble should be experienced as long as the metal does not get too low in silicon or too high in sulphur.

As can be seen by a study of Chapter XXXI., it is the changeable character of silicon and sulphur which alters the "grade" in the product of a furnace as long as it is running on one class of ore, flux and fuel. Could the sulphur and silicon be controlled in or out of the furnace so as to have the liquid metal always possessing its metalloids constant, the present great objections to the use of direct metal in making castings would be removed.

To eliminate sulphur or silicon, etc., from direct metal, is causing much labor and study, in order to obtain, if possible, means to achieve success in this line. One method at present being conducted is that of Mr. E. A. Uehling, patented in papers No. 543,115, granted July 23, 1895, in which the principle involved is to suspend a large revolving ball of certain materials in a ladle of liquid metal that may have an affinity for whatever metalloid is desired to be reduced or eliminated.

At this writing, the author is informed that the Sloss Iron & Steel Co., of Birmingham, Ala., is fitting up to give Mr. Uehling's plan a practical test. To give an idea of Mr. Uehling's method in applying elements having an affinity for the metalloids, we present the following extract, which is taken from his patent papers:

"According to the nature of the elements of which the revolving bodies are composed and the end to be effected, these bodies are assimilated by the molten metal, or absorb from the same injurious elements, forming a slag, which separates by gravity from the body of the metal, rising to the top, where it can be removed. For example, if the revolving body or bodies are composed of carbon, and the molten metal which is agitated by them is deficient in the element, it will be absorbed and assimilated by the metal. If the revolving body is composed of silicon, manganese or aluminum, these elements will first satisfy their affinity for oxygen and the excess will be assimilated by the metal. Manganese has in addition to its affinity for oxygen also a great attraction for sulphur and is very efficient in separating this most injurious element from the metal thus treated. If the revolving body is composed of oxide of iron in connection with other basic material, the silicon will be removed from the metal bath, and under favorable circumstances also the phosphorus."

As Mr. Uehling has been very successful with other improvements which he has made towards advancing blast furnace work, we have every reason to believe that he will meet with success with the above apparatus for the elimination of what metalloids he desires to control.*

*As this chapter was going to press, the author was informed that Mr. Uehling was meeting with much success and had reduced silicon from 2.85 down to .67 and phosphorus from .65 to .47, at the Sloss Iron & Steel Co.'s plant. There is no doubt that sulphur can also be easily eliminated. It is hard to predict what changes in founding this or similar processes may make in carrying us back again, with many branches, to the old days of using direct metal.

CHAPTER XI.

BLAST FURNACE vs. CUPOLA PRACTICE.

"BANKING" FURNACES AND CUPOLAS.

The principle involved in "banking" is simply to do all possible to prevent any air finding access through the body of a furnace to the fuel, so as to stop rapid combustion and sustain the fire only in a dormant state until it is found desirable to again "blow in" the furnace. This is similar in principle to the practice of smothering a fire in a stove over night so that next morning little labor or fuel would be required to start a good fire and provide a quick breakfast. The old plan of "banking" a furnace involves considerable labor and expense. One system followed is to encircle the furnace with a curbing of plates bolted together, or planks stood on end, projecting 2 or 3 feet above the tuyeres, the planks being held together by means of hemp or wire ropes, the space between the furnace and the curbing being about 2 feet, which is filled up with a close grade of sand. Before encircling the furnace with this curbing, the slag pipe and the tuyeres are all taken out and all their pipe connections removed. (The pipe connections to the coolers are not disturbed, as water is left on them during the time of "banking.") After this the tuyere holes in the brickwork, etc., are filled

with clay. This system makes it almost impossible for any air to find access to fuel in the hearth, where so many openings for tuyeres, etc., would leave crevices for air to enter. The stack portion being practically a solid body enclosed by a tight shell of iron, no attention is given to it; so also with the bell and hopper at the top of the furnace, as some ventilation is desirable at the top to allow any excess of gas to freely escape. For this purpose, the "bleeder" pipe valve can be forced open, as in no case is the "down comer" valve opened. From this "bleeder" the state of the fire in the furnace can also be fairly judged. Nearly all furnacemen differ somewhat in their methods of "banking." At the present day many have abandoned the practice of encircling a furnace with a curbing above described, and after removal of the tuyeres and pipes they simply pack all holes and crevices with clay rammed tightly in place, and then occasionally wash the outside of the lining or brick-work, which is exposed to the air, with a thick coat of clay wash, thus closing up all crevices or pores which might admit air to the fuel. This plan, while costing much less than the curbing system, has been found sufficiently effective to answer all purposes. In preparing the furnace for being "banked," it is essential to free it as much as possible from its regular charges, and any liquid metal which may be in the hearth below the tapping hole.

To liberate the liquid metal all that is possible from the bed of the furnace, a hole is sometimes made from one to two feet below the level of the top of the regular tapping hole, which permits the metal to run out in an excavation made in the ground in the form

of a long runner, so that what flows out below the level of the tap-hole can be broken up. This plan is one adopted for "blowing-out" as well as "banking." As will be seen by Fig. 11, page 97, there are often very large bodies of metal below the tap-hole. Even by the plan just described these are rarely ever all drained from a furnace, always leaving some to solidify that will have to be brought back to a liquid state when the furnace is "blown in," requiring as a general thing but a few days.

The first move in preparing to "bank" a furnace is to discontinue its charges of ore and lime in the regular way and to admit chiefly fuel, in order to keep the furnace filled, occasionally dumping a little ore and lime to divide the fuel and to destroy the union of a solid combustible body of fuel and thereby assist in smothering combustion. As soon as it is found that the last regular charge of ore, lime and coke has passed the level of the tuyeres, the furnace is tapped and an extra pressure of blast applied so as to force out all metal possible. This done, the blast is shut off and the "banking" operation commenced. When this is completed the furnace is filled up with fuel, etc., as above described, and in some cases the surface of the last charge is covered over with fine ore or loam sand to assist in shutting off draft, in which state the furnace is left standing. As a general thing, wherever sand can be used for banking, it is preferable to clay, as the latter is apt to crack in drying and leave crevices whereby air can find access to the fire to excite combustion.

In some cases the fire may lie dormant in a good condition for six months or more without any renewal

of fuel, but this is seldom done. If, after three or six months of banking, it is found that conditions of trade, etc., will not demand "blowing in," as anticipated when first banking the furnace, the fires will often be allowed to die out, in order to make preparations for "shoveling out," so as to discover if a furnace requires re-lining in parts or as a whole.

A good illustration of the extent to which banking a furnace may be carried is that conducted under the able management of Mr. C. I. Rader, during the years 1893–95, at the Paxton Furnace, Harrisburgh, Pa. Furnace No. 1 at this place was banked August, 1893, and not opened until June, 1895, a period of one year and ten months, at which time the furnace was found in a condition to be successfully "blown in." Mr. Rader says a light ore burden and half coke and anthracite were used in banking down the furnace, and the top covered with a layer of fine ore. This is the longest period of successful "banking" of which the author has any record.

When "blowing in" a "banked furnace," the first operation is to clean out the tuyere holes, etc., of their clay and sand packing, after which the refuse and dead ash in the furnace are pulled and shoveled out through the tuyere openings and slag holes, so far as possible. This done, the tuyeres are replaced and their water and blast connections completed. A heavy bed of fuel is now charged, after which charges of ore, lime and fuel are delivered into the furnace. The burden of ore and lime is gradually increased in weight in the first charges until several are delivered, when the regular burden is then charged on. The blast being on, the furnace is again in condition to make iron. For the

first two "casts" or day's run a furnace is liable to work cold, which results in giving a low-grade metal or iron high in sulphur and low in silicon. As a general thing, furnaces are compelled to use cold blast when "blowing in," for the reason that there is no gas to make the hot blast ovens operative until after a furnace becomes sufficiently heated to have gas pass down the "down-comer" to the ovens. A few plants, like that of the Carnegie Steel Co., having several furnaces connected or in close vicinity, can bring hot blast from other furnaces until the "blown in" furnace gets under way. Where cold blast has to be used at the start, it takes much longer to get a high-grade iron than where hot blast can be obtained. With hot blast they may often, at the very first "cast," secure high grade iron, whereas with cold blast it may take a dozen "casts" or more to do so, and in either case, the largest output is not generally obtained until a furnace has been in blast from one to three months.

Those founders inexperienced with furnace work can well imagine from the description here cited that although "banking" is a compromise to "blowing out," which means a complete shut-down, the furnace manager is desirous of avoiding such manipulations so far as possible, as the expense is by no means light, and many sacrifices will generally be made in having capital lying idle in piles of pig iron in order to run a furnace steadily, rather than "banking" to await increase of orders or a demand for their product. If furnacemen have any assurance that they will not "blow in" after three months' "banking," they will generally "blow out," as the accumulation of ash and dirt from a furnace banked to exceed three months

is such as to be very apt to make it difficult to get a furnace working well for a week or more after it is "blown in."

Banking is generally done in cases where a shut-down is thought to be only temporary. If a furnace "blows out," which means a clear shut-down, nearly the same amount of fuel and lime is often charged to follow the stock down as if the furnace was being "banked." This is done so as to burden the blast and keep the heat or flame of the furnace from escaping and thus better reduce the stock of ore to metal and also cause less heat to affect the upper lining as well as the bell and hopper from melting, and makes a cleaner furnace when "shoveled out." There are a few that will "blow out" a furnace without covering the last charge of ore well with fuel and lime, but this plan is not considered good and safe furnace practice.

In "blowing out" a furnace, the fuel used to follow the stock down can be largely saved, for as soon as the last tap of iron is made, and the blast shut off, the tuyeres P, Fig. 6, page 71, can be all pulled out and the incandescent fuel raked out on to the ground floor, where with a hose, water will soon dampen the fire in the fuel, which will be found to be but little burned, so that it can be used over again. After the fuel is all pulled out level with the tuyere, water can then be thrown by a hose to dampen the fire in the hearth, so that in six to ten hours after the blast is stopped all fire can be extinguished.

Where banking a cupola might be thought of, as referred to at the close of this paper, it is generally well to have a charge of fuel follow the last charge of iron,

as this would assist better in closing off all draft than were the last charge all iron, as a fine dust fuel, ore, etc., could be used on the surface to close up all cavities without calling for enough to cause injury, as would be the case with fine stock used to close up the cavities between pieces of iron, instead of fuel.

The principle involved in "banking" a furnace is one that has to a slight degree been practiced by some founders, as is seen in "American Foundry Practice," page 301. The author is so sanguine that the principles involved in banking are practical for application in cupola work, that he lately remodeled one of his cupolas with a view of experimenting to avoid the necessity of dropping the bottom at every heat. It is to be regretted that at this writing conditions in our shop work have not permitted giving it a trial, the reason for which lies in the fact that the cupola which was prepared for this experiment was not large enough to run the heats demanded. The plans followed in remodeling this cupola consist simply in making all tuyere connections air-tight, raising the spout so as to permit of from two to four inches of a heavier sand bottom, also in providing a double slide arrangement facing the tuyere openings which, when both were closed, left a space between them to be filled with loose sand that could be readily removed by a little slide pocket in the bottom of the sand space. These two factors, combined with an arrangement to positively shut off the admission of any air where the main blast-pipe is connected with the wind-box, completed the arrangements. With this device it is the intention, after the first heat has been run off, if not a large one, to thoroughly melt down any iron that

may be in the cupola, after which the breast will be opened and all dead ash and refuse lying in the "bed" will be raked out. After all dead material has been thus cleaned out, the breast will be firmly sealed up with tightly rammed sand, and all tuyere connections, etc., closed as above described. A little extra fuel being now put in and the top charging door closely sealed, the cupola will be allowed to stand in this condition until time to charge for the next heat, when the "bed" will be "replenished," the cupola re-charged, and, after the breast has been replaced, the heat proceeded with as usual. How many times this operation can be repeated without "dropping the bottom" can only be told by practice. In endeavoring to follow such a practice the management of the cupola must be in intelligent hands, as it can be readily seen that to charge a cupola ignorantly or carelessly, as is often done, would result in leaving iron at a level with the tuyeres, or all on one side of the cupola, so that it could not be melted at the end of a heat. These ideas are not presented with the expectation that all founders are going to drop their present methods to adopt the plans outlined; they are simply offered as suggestions to evolve ideas which may favor the inauguration of new practices that to-day might seem absurd and impracticable.

John C. Knoeppel, of the Buffalo Forge Co., Buffalo, N. Y., recently related to the author an experience in banking a cupola, which may often prove of benefit. In brief it is as follows: The blast had just been started and the iron was not yet down, when an accident occurred to the machinery, stopping the blast. As the damage could not be repaired before

the lapse of many hours, Mr. Knoeppel simply closed all air openings tightly with clay and sand, and covered the top of the stock at the charging door with fine dust coke. When the blast was started, about sixteen hours after the shut-down, the melting went on in good shape, as in the usual practice. This was done in a cupola of about 56 inches inside diameter. One factor assisting to make Mr. Knoeppel's plan so successful was the fact of the iron not having started to melt when the break-down occurred. Mr. Knoeppel's experience, combined with that recited by the author in "American Foundry Practice," above noted, may suggest expedients often profitable to be adopted.

CHAPTER XII.

BLAST FURNACE vs. CUPOLA PRACTICE.

HOT AND COLD BLAST VS. COMBUSTION AND HEAT.

There are four terms applied to blast in driving the oxygen of the air to combine with the carbon in fuel to support combustion. The first is called "cold blast," the second "warm blast," the third "hot blast," the fourth "superheated blast." Cold blast is such as is generally employed by founders in remelting metals in a cupola, air or crucible furnace, also charcoal blast furnace. Warm, hot and superheated blasts are those generally used for smelting ores to produce iron or other metals. Warm blast is air heated from about 250 to 400 degrees F. Blast heated above 1,100 degrees F. is generally termed superheated blast, and temperature ranging between 700 and 1,100 degrees F. is known as hot blast. There are two properties to blast, the first being physical and the second chemical. In the first element we have weight. Marriotte's law of volume being inversely proportional to the pressure, is one closely defining the weight of air, but late experiments have found different gases to vary somewhat from Marriotte's laws in their compressibility. With a temperature of 60 degrees F. and the barometer at 30 inches, air weighs about one eight-hun-

dred-fifteenth part as much as water. The weight of blast passing through a furnace in smelting ore to produce iron is greater than that combined of all the fuels, ore and flux charged.

The chemical properties of blast or atmospheric air are recognized as chiefly containing a mixture of two gases, nitrogen and oxygen, which by volume and weight are recorded in Table 13.

TABLE 13.

	Volume.	Weight.
Nitrogen	79.19	76.99
Oxygen	20.81	23.01
	100.00	100.00

Nitrogen, it is claimed, is practically ineffective in playing any part as far as it relates to any necessity of considering it in furnace or cupola work. As oxygen and carbon are the chief factors necessary to support combustion, we will first note their influence in obtaining perfect combustion. According to Dulong, 1 pound of carbon combining with the necessary quantity of oxygen to form carbonic acid develops 12,906 units of heat. The specific heat of cast being about 13, the melting point 2,190 degrees, and the coke containing 82 per cent. of carbon, then to heat a ton of cast of a temperature of, say, 40 degrees to a temperature of 2,190 degrees, would require $\frac{2150 \times 2240 \times .13}{12906 \times .82} = 59.1$ pounds of coke. This is supposing that the whole of the carbon is converted into carbonic acid; but if by any means carbonic oxide is formed, a very different result is obtained; then one pound of carbon to carbonic oxide

only evolves 4,453 units of heat. If, however, by admitting air above the zone where the oxide is formed we recover 4,478 units, this time 4,453 gives 8,931, which is a little over two-thirds of the available heat to be gotten out of one pound of carbon. Allowing 10 per cent. for moisture in the coke, 10 per cent. for radiation and 20 per cent. for loss of heat passing off at the top of the cupola, or 40 per cent. in all, the amount of coke per ton of metal should not exceed 112 pounds, although the actual consumption is, as we have shown, usually much higher.

The combination of carbon with oxygen or air blown through the "lower tuyeres" produces carbonic acid gas in the bottom bed of fuel and this in passing up through fuel heated to incandescence takes up more carbon and is converted into carbonic oxide gas. Now, if the carbonic oxide can again have sufficient oxygen or air admitted to it, we will again have carbonic acid or more nearly complete combustion, and by such alternate zones which at every repetition become less violent, we could, if it were only practical to hit the right spot of the descending stock with the proper amount of air, almost achieve the theoretical figure of melting one ton of iron with 59 pounds of fuel, as given in above Table; but instead of that, many consider that if they can accomplish this with 200 pounds of fuel, or 1 to 10, they are doing good work.

We have cupolas figured to achieve the above results by reason of "upper tuyeres" or "center-blast," and all such are really the only ones properly entitled to the claim of being scientifically constructed as far as the admission of blast is concerned. Were it only possible for the blasts passing through upper tuyeres

to penetrate to the center of the cupola and have an immovable zone of fuel to play into, they might successfully accomplish the end intended, but as it is, the results are but partial; and it is a question if the extra burning out of the lining which two or more rows of tuyeres caused by having more melting zones does not often more than compensate for what saving in fuel may be acquired.

It is stated above that nitrogen is claimed to be inert in combustion. The author does not quite agree with this conclusion, and would differ in claiming that it plays a part in cooling off a furnace or cupola wherever excessive blast is used. Table 13 shows that there is nearly three times as much nitrogen as oxygen in the air. While it is no doubt true nitrogen is inert in promoting combustion, it cannot but be evident that the more nitrogen blown into incandescent fuel, just so much more heat must be extracted from the burning carbon to raise the nitrogen to the same temperature as the heat in the interior of a furnace or cupola. In this hypothesis, the author believes, lies the secret of the damage that too much blast can cause in making as well as re-melting iron. If the greater volume of air could only have its oxygen increased proportionally without increasing nitrogen, we would then find that much less pressure or volume of air would be effective in aiding rapid and thorough combustion, than is the case under present natural conditions. Then, again, it can be readily seen that where there is any increase in the humidity of the air, as defined in Chapters XIII. and XXXIX., the increased nitrogen serves as a good sponge to carry the moisture of the air to the fuel, so as to lower the temperature or

call for more fuel to obtain the temperature required, which increase of fuel causes a slower driving of the furnace or cupola.

This discussion of nitrogen leads us to consider the effect of hydrogen in combustion, which, as found in water combined with oxygen, exists by weight in the proportion of one for hydrogen and eight for oxygen. In this proportion these elements are ineffective to promote combustion, but if by any reason we can separate these gases, then they can be of a temporary benefit to incite combustion or heat. Some have argued that because hydrogen and oxygen can be made to produce great heat by means of oxygen or hydrogen blow-pipes, waterlogged fuel or air assists instead of retards combustion. If it were not true, as has been found by experiments, that the heat absorbed by water or steam to decompose or separate its compounds of hydrogen and oxygen was not more than enough to counterbalance the temporary effects of these gases being set free to incite combustion, we would then be right in expecting the separation of these elements to be a truly beneficial aid to permanent combustion. We can not illustrate this principle better than by noting the effects of throwing a pail of water into a large body of incandescent fuel, such as exists at the dropping of a cupola's bottom. Here we see the elements separated and hydrogen caused to burn with a blue flame, while the oxygen will unite with the carbon of the fuel and give a sudden impetuosity to the combustion for a few moments, when the reaction of the heat extracted to separate these elements of the water or steam will cause the fire to deaden and suddenly become lower in its temperature. Water or steam, if

administered in a spray of little volume, may in some cases excite combustion; but, as suggested above, the heat extracted to do this more than counterbalances any good done as regards economy in fuel, so that in treating of combustion as utilized in making or remelting iron, we are right in ignoring the effects of hydrogen and confining ourselves to an acceptance of oxygen and carbon only, as being the essentials to be considered as the elements affecting combustion, as met with in daily practice. And this brings us back to Mother Earth, to define results as they actually exist in order to prove of value to combustion.

The more carbon is in a state of carbonic oxide the less heat the ascending gases contain for fusing iron or reducing the ores. The greatest practical economy of fuel that can be attained in a furnace is secured when the gases contain such a small percentage of carbonic oxide that when they leave the furnace to escape down the "down-comer" or pass out of the cupola, their temperature is so low as to be insufficient to heat iron red hot or reduce any more ore.

The ideal of combustion in a furnace or cupola would be to have all the carbonic oxide completely utilized so that what carbon might escape should only be in the form of carbonic acid passing down the "down-comer" or escaping into the open air from the top of a furnace or cupola. As the gases pass up a furnace they collect some oxygen from the ore, the amount of which is dependent upon the molecular nature of the ore and the percentage of carbonic oxide in the gas. This fresh addition of oxygen derived from the ore is similar in its influence upon combustion to the oxygen which is extracted from the air or blast and retards the

formation of carbonic oxide, so as to render assistance to the ascending gases in their effort to maintain the gas more in a state of carbonic acid, which, as stated elsewhere, is that state creating perfect combustion. The percentage in which gas can hold carbonic oxide and carbonic acid to predominate in one state or another can vary, and is dependent upon the temperature of the furnace and nature of the stock to be reduced.

Excessive blast. Every observing founder has noticed that after a certain volume of blast was used the speed of melting would often be more retarded than advanced. Shops having a large and small cupola side by side, blown with the one fan or blower, have an excellent chance for noting whether an excess of blast can be beneficial or not, as it is an easy matter to apply the same pressure and volume to the small cupola as was found to work well in the large one. Why the excess of blast in the small cupola, or any size, is injurious can be explained as follows: In blowing a cupola, the carbon of the fuel can be liberated to cause the most economical combustion just to the extent that carbonic acid gas is created. In one row of tuyeres this is only achieved in front of and above the tuyeres, to the height of the "melting point." Any excess of air that cannot combine with the fuel to create carbonic acid gas then passes off as carbonic oxide gas, only carrying off heat and solid carbon, instead of promoting combustion, which if taken in connection with the effects of increased nitrogen, as treated on page 139, will still further illustrate the evils of excessive blast in being destructive to fuel and in lessening speed in smelting or melting.

The following Tables 14, 15 and 16 show the amount of heat absorbed in smelting and that lost by radiation and in the gases, according to Sir Lowthian Bell's estimate, expressed in hundredth-weight heat units per ton of iron produced:

TABLE 14.—HEAT PRODUCTION.

Oxidation of carbon	81,536 units	
Contributed by blast	11,919 "	
		93,455

TABLE 15.—HEAT ABSORPTION.

Evaporation of water in coke	312 units	
Reduction of iron	33,108 "	
Carbon impregnation	1,440 "	
Expulsion of CO_2 from limestone	5,054 "	
Decomposition of CO_2	5,248 "	
Decomposition of water in blast	2,720 "	
Phosphorus, silicon and sulphur reduced	4,174 "	
Fusion of pig iron	6,600 "	
Fusion of slag	16,720 "	
		75,376

TABLE 16.—HEAT LOSS.

Transmission through walls of furnace	3,658 units	
Carried off in tuyere water	1,818 "	
Carried off in gases	8,860 "	
Expansion of blast, loss of hearth, etc.	3,743 "	
		18,079
		93,455

By increasing the height of furnaces from seventy to one hundred feet, as practiced at the present day, much more heat is utilized than was formerly the case when furnaces were about forty to fifty feet high. This practice has also resulted in causing furnacemen to make No. 1 iron, whereas with low furnaces and high pressure of blast they could only make No. 2 iron. This experience is one which the founder has also found advisable to follow in the construction of cupolas, as they are made to-day from four to twenty feet higher

than they were about fifteen years ago. The height now generally followed is about twelve feet from the bottom plate to the lower level of the charging door, whereas it used to be only from six to nine feet. The Carnegie Steel Co. has cupolas as high as thirty feet to the charging ring.

No cupola should be less than 10 feet from the bottom plate to the charging door, and the larger the cupola the greater the necessity for height to utilize the escaping heat. As a rule, the height to the charging door should be 3½ times the inside diameter for cupolas between 30 inches and 40 inches, and above this to 60 inches, three times the diameter in height, and so on according to size.

As the carbonic oxide soon gains supremacy over the carbonic acid in the process of smelting or melting, it is not long before we find that the gases in ascending a furnace or cupola from the level of the tuyeres have changed their composition from that necessary for perfect combustion. By this I do not mean that unless there are two atoms of oxygen to one of carbon there cannot be any reduction in bringing the ores to a plastic state in furnace work. By considering that a state of carbonic acid is necessary to liquidize, and that carbon-oxide can only fuse to a plastic or partially molten state, we are in a position to comprehend the difference in degrees of temperature which ascending gases can effect in reducing ores and causing them to drop in a fluid state into the crucible or hearth of a furnace.

Sir Lowthian Bell has found that as the gas creates carbonic acid upon meeting the incandescent fuel at the tuyeres, it instantly absorbs more carbon and be-

comes carbonic oxide. This action of the carbonic acid, in dissolving the carbon of the fuel, continues until the gases have risen in the furnace to a height where the temperature has decreased to about 1,500 degrees F., when, according to Bell, this action then ceases. He has also found that carbon commences to reduce peroxide with some formation of carbonic acid, but chiefly carbonic oxide, at a temperature of about 800 degrees F. He further concludes that carbon, or carbonic oxide, can cause a reduction of the ores in the absence of carbonic acid in the upper zones, but whether the carbon or carbonic oxide would predominate in their control of the action is dependent on the temperature at different levels in the upper zones of a furnace. Bell also argues that it is very important that ore should be de-oxidized before it reaches a zone where carbon becomes, from elevation of temperature, the reducing agent and carbonic oxide is the main product. He maintains that this arises from the circumstance that one unit of carbon passing to the state of carbonic oxide only affords 24 centigrade units of heat or calories, but when it passes into the condition of carbonic acid from carbonic oxide, 5,600 additional calories or units of heat are evolved. This should plainly illustrate the difference in temperature which the two states of carbonic acid and carbonic oxide create in a cupola. It also demonstrates to the founder and moulder why upper tuyeres, or a higher opening from "center-blasts" in a cupola, create two melting zones, due to admitting another stratum of air, thereby causing the escaping carbonic oxide to receive a fresh supply of oxygen sufficient to create carbonic acid, which, as shown by Bell, is a state of gas

containing 5,600 more units of heat than when the carbon is in the form of carbonic oxide.

Bell's tables of escaping gases* show the carbon much in excess of the oxygen, in the proportion necessary for perfect combustion, and demonstrate the importance of designing furnaces and cupolas so as to supply them with oxygen at different zones, in order to lessen the percentage of carbonic oxide which may escape. Oxygen, being derived from the ore charged into a furnace, assists in adding oxygen to the solid carbon of the fuel in its descent to the fusing zone, and to a slight degree this answers the purpose of upper tuyeres in smelting. With cupolas in remelting iron, we have no material from which oxygen can be extracted the same as in a furnace, as iron contributes little if any oxygen; and hence we find the utility of upper tuyeres or "center-blast" in a cupola arranged so as to admit an upper stratum of air or oxygen, in order to lessen the escape of carbonic oxide and thus give better or more perfect combustion. As upper tuyeres often more than counterbalance their economy in fuel by reason of burning out lining, the "center-blast" more than ever appeals to our reason as possessing the qualities so desirable in obtaining the best all-around economy in general cupola practice.

* Journal of the Iron and Steel Institute, vol. 2, 1887.

CHAPTER XIII.

EFFECTS OF BLAST TEMPERATURES IN DRIVING FURNACES.

Hot blast is claimed to have been first introduced by Mr. James Beaumont in Scotland in 1825. Up to this time cold blast only had been used. The use of hot blast has increased in temperatures from 100 to 1,500 degrees and over. Every increase in temperature in blast was found to effect more or less of a saving in fuel and improve the working of a furnace up to 1,700 degrees; over this it has not proved economical. When only 100 degrees was used it proved to be an advantage over cold blast. Then came 200 degrees, showing better results than 100 degrees, followed by 300 and 400 degrees, on upward until a temperature of 1,000 degrees was obtained, which was as high as iron stoves or pipes would stand the heat without being rapidly burned away. The knowledge that every increase in temperature had proved beneficial gave confidence that a higher temperature than 1,000 degrees would still continue to prove economical, but in order to utilize a higher heat than 1,000 degrees, some other plan than "iron stoves" had to be devised. This new type was not long in making its appearance. Different designs of stoves having all-brick flues which could not be damaged to any radical degree

were introduced with great success, and the temperature of the blast was soon raised by degrees until 1,500 to 1,600 degrees were often utilized with benefit where a furnace had "chilled" or "got off;" but the general practice of high temperature with blast in the normal working of a furnace is not to exceed 1,300 degrees, being kept at 1,100 to 1,200 degrees with brick stoves and 800 to 1,000 degrees with iron stoves. When a furnace is working well, any increase over 1,200 degrees in the temperature of the blast is claimed by many to be more injurious in its results on the stock than beneficial in assisting a furnace to produce a good yield of iron, or "drive well." Why high degrees of heat in the blast will not cause the reduction of ore in the furnace that high heat derived from a fuel will, is a phenomenon which all seem at a loss to understand. Experience has demonstrated that a temperature between 1,000 and 1,200 degrees is the most desirable to maintain. A blast may have its temperature raised from 600 to 800 degrees with but little improvement noticed, but let this 200 degrees increase be added to 1,000 degrees and the benefit derived is extraordinarily above that of any increase of 200 degrees from lower temperature. In the normal working of a furnace the best results are obtained with a temperature of blast ranging between 1,000 and 1,200 degrees F.

By reason of utilizing the waste gases of a furnace to heat cold blast, blast furnace practice excels all other industries in obtaining the greatest efficiency from fuel, as about 75 per cent. of the heat generated from the solid fuel is utilized. This is attained where one ton of coke will produce one ton of iron; and

where this is done Sir Lowthian Bell claims that all the economy is achieved that is practical to be expected in making iron, as long as the present fuel is used. To observe the manner in which heat is produced, absorbed and lost, see Tables 14, 15 and 16, page 143.

Pyrometers. Various methods are employed for measuring degrees of heat. Those of a crude nature consist, for example, in using dry sticks of wood, which when inserted in hot air take fire, indicating a temperature of about 650 degrees F. Again, sticks of zinc, if melted, indicate about 750 degrees. To obtain a record of higher temperatures in a more accurate manner, many different kinds of instruments have been devised and of recent years have been largely adopted. A pyrometer recently designed and patented by Mr. E. A. Uehling, of Birmingham, Ala., in which the expansion and contraction of air between two small apertures are the principle used to denote temperature, is claimed to be giving excellent satisfaction. It is being largely adopted by blast furnacemen to record for them any variations in the temperatures of the hot blast or escaping gases, and enables them to regulate the workings of a furnace so as to give a greater output and produce a more uniform product than heretofore.

The question of temperatures in driving a furnace fast or slowly is one of interest. It will appear odd to the founder, as well as to others, that a furnace can be got so "hot" as to retard the speed of making iron, and also may result in "scaffolding;" nevertheless there is a limit to attaining temperatures best calculated to drive a furnace to its utmost, which means obtaining the largest tonnage possible in making iron.

After this limit is reached, it would appear as if too great a body of the ore were suddenly brought to such a swollen, gummy state, as to retard the proper ascent of the blast and gases. The first factor to give notice that a furnace is getting "hot" is an increase in the temperature of the gases and the refusal of the stock to descend as rapidly as when the furnace is working in a normal condition. To retard the increase of heat or lower the temperatures to the best point, it has been found that increasing the blast pressure would often bring a "hot furnace" back to its normal working. By this action a greater volume of blast is admitted, which having a lower temperature than the incandescent stock in the furnace, naturally cools it down. Then, again, a plan is now largely adopted in having arrangements made so that cold blast can be turned on at a moment's notice. This "brings a furnace 'round" more quickly and in a much better manner than by increasing the pressure of the regular blast which, it should be understood, will have its temperatures lowered as much as is practical before being admitted.

It is chiefly with brick hot-blast stoves that arrangements are provided for admitting cold blast to cool off a furnace, as these carry higher temperatures of blast than iron hot-blast stoves, as can be seen by referring to Chapter XIV. The causes leading to "hot" furnaces can be traced to excess of fuel, often brought about by using larger percentages than ordinary, which may be called for by reason of having to use small, or what is thought to be inferior coke or fuel, and again in burdening a furnace with fuel in order to raise the silicon in the iron or guard against "scaffolding" or "slips" from the use of fine ores, etc. It may also be

caused by a furnace perfecting combustion of its own accord to such a point as to overreach the best temperature for driving well. It may be said that brick stoves have many advantages over iron stoves in permitting a furnaceman to regulate the temperature of his furnace so as to drive it well and increase or diminish the silicon or sulphur in the iron, and that a radical change is generally noticed in this direction when cooling down a "hot furnace," as by such procedure the silicon is often materially decreased and sulphur increased.

Humidity of blast. It is generally conceded by experienced furnacemen that a furnace will work better and produce more iron in cold than in hot weather. June, July and August are said to never produce tonnage to equal other months in the year. The air is generally dryer in cool than in warm weather, and it is now an accepted fact that the extra humidity in the summer air over that in cold weather is the cause of the less tonnage for the summer months. Some will think the heat imparted to the blast would drive out all the moisture, but this is claimed to be simply transformed into a vapor which passes into the furnace as steam. It has been estimated that twenty tons of water are often transferred by the blast to the interior of a furnace per day by reason of the high humidity of air in summer months. Further comments on this subject can be found in Chapters XII. and XXXIX.

CHAPTER XIV.

PLANS AND METHODS IN WORKING BRICK AND IRON STOVES IN CREATING HOT BLAST.

A knowledge of methods used in creating hot blast at the blast furnace is valuable to the founder and moulder in that it presents ideas for the benefit of those desiring to design appliances for the purpose of creating warm or hot blast for any purposes.

The terms "iron stoves" and "brick stoves" are understood to mean, in the case of the former, that the cold air passes through iron pipes, while with the latter, in being heated to make hot blast, it passes through flues or checkered work composed wholly of fire brick.

The iron stove is fast disappearing and being replaced by the brick stove, owing to the ability of the latter to create the highest temperatures in blast, which allows iron to be made more cheaply than where a temperature no higher than 1,100 degrees F. can be created, as with iron stoves. A further reason for this displacement is that the brick stove is less expensive, in matters pertaining to repairs and "shut-downs," to keep a furnace running steadily, also in giving more gas for use under boilers, etc. than iron stoves.

The operations of brick and iron stoves differ in their methods of being "in blast." The brick stoves generally go out of blast every hour, whereas the iron

stoves general
for six week
and have be
run without in
several mo
This differen
their operatio
due to the pri
involved in
stoves requiri
cold air to ab
heat from the
comprising the
in the ovens,
the combustib
heating gases
all been shut
and in the "
stoves" by r
of the iron
or flues thr
which the cold
air passes, being separated
from union
with the gases; hence the
iron stove can
run steadily,
whereas the
brick stove
runs only at
intervals.

FIG. 27.—MASSICK & CROOKE PATENT BRICK HOT BLAST STOVE.

The short duration of the brick stove being "in blast" is due to the rapidity with which the introduction of cold air abstracts heat from the brick work. The temperature of a brick stove decreases from 100 to 300 degrees F. in one hour's time. With the plan

FIG. 28.—IRON HOT BLAST STOVE.

of stove shown at Fig. 27 there are four stoves required to keep a furnace steadily in blast. Of the four stoves, only one is generally in blast, although two may run together for the whole of one turn of the stoves. The plan generally followed is to "put on" the stove going

in blast a few minutes before the one going out of blast is shut off.

The sectional views of iron and brick hot blast stoves shown in Figs. 27 and 28, respectively, are of stoves in use within a "stone's throw" of the author's foundry. The brick stoves shown are of the most modern type, recently built, and are said to be giving excellent satisfaction. Before these stoves were built, iron ones were used by the same furnace. The four stoves are said to have cost $40,000, and by their adoption the owners were enabled to produce pig iron 30 cents per ton cheaper than when the iron stoves were used, owing to the brick stoves causing the furnace to use less fuel and give a larger yield of iron, also cheaper cost of repairs from those required in iron stoves. It may seem a small saving for the investment of $40,000. When pig iron was selling for from $30 to $50 per ton and the furnaceman had a margin of profit of from $15 to $30, no one thought of investing $40,000 just to save 30 cents per ton on iron made. When $10 to $12 per ton is about all a furnaceman can get for his iron, as is now often the case, a saving of 25 per cent. is quite an item, especially so if it will admit one furnaceman underselling another and leave a few cents profit on his sales.

There are several different types of brick hot blast stoves now in use, and it now seems as if it will be but a few years before iron stoves will be almost wholly abandoned, mainly because the brick stove can make iron more cheaply than the iron stove. A large number of furnaces are still using iron stoves, but as soon as they are worn out, or competition gets too keen, they will no doubt be largely replaced by the brick stoves.

However, a description of some of the main features and principles involved in "iron stoves" cannot but be of value to many.

The plans and workings of an iron stove should first be considered. There are several different methods used in piping an iron stove. Those commonly employed are with the inverted U and straight pipes, as shown in Figs. 29 and 29A. The inverted U pipe in Fig. 29 is the same as those used in the iron stove illustrated in Fig. 28. This oven contains forty-four of such pipes, there being eleven in a row and four rows in the length of the oven. The length and height of the oven are shown. The width is twelve feet. As the pipes stand up in the oven there is about three inches space between them. The knobs seen at T, Fig. 29, form the space of division between them. The section seen in Fig. 29A, page 157, is what is called "straight pipe." The division bar X answers the same purpose as making the pipes of a U form, owing to the rib X running up within about six inches of the top end of the pipe, when erected in the oven. A similar partition as at X is also in the bed pipe; this causes the blast to pass up one side and come down the other, thus serving the same purpose as the pipe at Fig. 29.

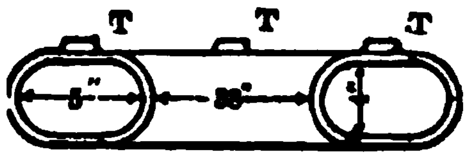


FIG. 29.

The straight pipes have the advantage of being more easily handled in taking them out of an oven when they burn out or crack, as they often do. The top of the oven is so constructed that the plate can be removed to permit bad pipes being hoisted out by means of an erected pole on the outside of the oven. It is far from being an easy or pleasant job to replace burnt

or worn-out pipes. For this reason much care is exercised to prevent the temperature rising above 1,100 degrees in the oven.

There is a plan used in iron stoves of suspending the iron pipes from the top of the oven instead of having them rest with their weight on the "bed pipe," as shown in Fig. 28. The plan prevents the iron pipes from "buckling" or bending from their own weight when they get red hot.

The general plan adopted for heating cold air to make "hot blast" in the iron stove will be readily understood by a study of the design illustrated in Fig. 28. The arrow seen at A, Fig. 28, is the point at which the cold air enters the iron pipes in the hot blast oven. As soon as the cold air enters the first "bed pipe" E, it takes the direction shown by the arrow in the pipe B; passing from this to the "bed pipe" F, then traveling up the pipe D and down into the bed pipe H, continuing such a line of travel through four to six more pipes, according to the length of an oven, until the blast reaches the outlet at K on the right, from which it then enters the blast furnace as "hot blast."

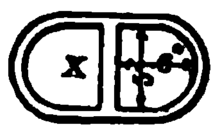


FIG. 29A.

The action of gases is next to be considered. An element to be understood is that of the means employed for heating the oven or iron pipes to create "hot blast." This is simply accomplished through the waste gases which escape at the top of a furnace, passing on down through the "down-comer," seen on the right, to a flue N N, and then rising into the ovens through the openings M and P, until they reach the combustion chamber R, where they ignite as soon as they reach the point S, by reason of the gas being met

by a fresh supply of oxygen or air and the heat of the oven. The chimney seen on top of the ovens at W creates a draft and permits the smoke or dead gas to escape. All the space about the pipes B and D is called the "combustion chamber," and when the gas is burning in the oven this space area is filled with a flaming gas fire.

Should the furnace go out of blast for any reason to exceed two hours, the oven will generally cool down to such a degree as to be very liable to cause an explosion when the gas begins to enter. Again, the oven being cold, could not heat the blast at the start to any effective degree, and hence less iron would be produced, with a chance of also promoting "chilling" in the furnace. To prevent or guard against such ill results, a wood or coal fire is generally built in flues P by opening the doors V. By such a plan the heat of the oven can be maintained to 700 to 800 degrees. It is not infrequent that items are noticed in the trade and daily papers speaking of some furnace having had a gas explosion. A cold oven is often the cause, and furnacemen watch this element very closely. Not only is it necessary that the ovens be hot when the gas from the ovens first enters them, but it is also desirable that a flame be burning in the oven to insure the gas igniting. Some furnacemen will take no chances in this respect. If they shut down but for half an hour they will either have some dry wood or a few lumps of soft coal placed in the oven so as to insure a flame therein when the furnace begins to send its gas down the "downcomer." A gas explosion can cause great damage, and the wise take no chances or risk with it.

The color of the gases escaping from the chimney

W, and also of the flame in the ovens, affords an experienced furnaceman much knowledge of the condition of a furnace or what results may be expected in its workings. In this respect, also in regard to explosions, the same is to be said of a brick stove as of the iron one. Notes on the color, etc., of gases and flame will be found on page . The gas, as it escapes from the top of a furnace in its passage downward to the iron or brick oven, is chiefly in the form of carbonic oxide and may often not have a temperature of 300 degrees of heat, although it generally ranges from 400 to 500 degrees as it passes through the "down-comer" to the ovens. This form of gas is an explosive, requiring air to make it combustible. This element it receives after it has entered the ovens, the air being drawn from outer channels or flues in the brick work of the iron stoves, as at H and F in the brick stove; this action creates the flame in the ovens just cited, which then raises the temperature to the degrees above noted. If the gas were allowed to pass into the oven in the state in which it comes from the top of a furnace through the "down-comer" without receiving a sufficient supply of air, the gas would be of little value in raising the temperature of the blast confined in the pipes on its passage to the furnace.

The plans and working of a brick stove are as follows: The line of the arrows seen in Fig. 27 displays the various channels through which the cold blast travels after entering the brick stove at E, seen at the end of the cold blast inlet pipe. The direction of the cold blast in being heated is directly opposite to that taken by the gas coming from the furnace to heat up the walls and various channels and checkered brick

work in the stove. This is the plan followed in all modern brick stoves. The gas in leaving the "down-comer" is carried through gas mains to V, where it passes the gas valve pipe at X to enter the furnace at H. Before the gas is turned on, the cap K, which closes the gas inlet while the blast is passing through the stove to be heated, is removed and the gas valve slid up so that the end of the pipe at X is about even with the face of the gas inlet. The pipe X, being smaller in diameter than the hole of the gas inlet at H, permits air to unite with the gas as it enters the stove, thereby causing combustion and ignition of the gas at the entrance before it passes to the combustion chamber, where it receives more air by means of the air inlet T, which is opened when the gas is turned on. At T, W and D are seen points at which valves are arranged for opening or closing the passage of air or gas, as the case may be. When the gas is being turned on, the valve D is opened. As now shown, it is closed so as to prevent any gas escaping up the chimney P. Before the gas is turned on, the valve D is opened so as to create draft and permit the dead gas and flames to escape through the chimney. The valves T and W are closed when the gas is on, as will be evident to any making a study of the plans shown. In a general way the blast is on a stove for one hour and the gas for three. Three stoves are generally on gas while one is in blast, unless one is being cleaned of the caked flue dust which rapidly gathers on the combustion chambers for a distance of about twenty feet in height, and on the bottom of the stoves, which have openings as at K and S for getting at or cleaning out the stove, or, if shut off, for repairs.

The valve at T is arranged with piping, through which water runs in order to protect the exposed parts of the valve from burning out. The valves W and D do not require the presence of water, for the reason that when the gas is on, the brick work of the stove absorbs the greatest heat at its bottom, which prevents the highest temperature being confined to the upper part of the stove. One stove, when a furnace is working well, is all that is generally "in blast;" but if there should be a "slip" to chill a furnace or make it work cold, two or three stoves are often put on at one time for a short duration to assist in raising the temperature in the furnace so as to restore it to its normal condition, after which the additional stoves are taken off and the work continued with but one, as in ordinary practice.

The four stoves are placed together as closely as is convenient to leave room for working around them. They cover an area of ground about 40x50 feet. The four stoves are connected by band pipes and separate valves, so that the cold blast coming from the "blowing tubes" and the hot blast leading to the four stoves come from and lead into one main pipe. The pipes which convey the hot blast to the furnace are either coated with an asbestos covering or have their interior lined with fire brick, the same as is done with the "down-comer" which carries the dead gas from the top of the furnace down to the combustion chamber of the hot blast stoves to protect them and prevent loss of heat.

CHAPTER XV.

UTILITY OF AND PLANS FOR HOT BLAST CUPOLAS.

The question is often asked, why "hot blast" would not work well and be more economical than cold blast for cupola practice. Every now and then some one is trying experiments in this line, believing he has original ideas which would work successfully. The author has thought an article on the subject, to illustrate what has been done and the success attending such experiments, could not but be of interest to founders and possibly be the means of saving time and money to any who might think to experiment in this line. For this reason the author presents herewith what information he has been able to obtain on the subject and also his own experiments, suggestions and ideas on this question.

Large stacks have been built on cupolas containing coils of piping so arranged that the blast would come in at the top and be carried through them to the tuyeres as heated air. The author has tried the plan of having cold blast pass through pipes suspended in the stack about four feet above the top of the charging door and having the hot air pass down to the tuyeres. Then, again, the plan has been tried of curving the stack and of carrying the escaping gases down to a

brick oven on the ground which was filled with coils of piping, all of these plans proving unsuccessful.

Neal Brothers, of Allegheny, Pa., are said to have used hot blast in a cupola for the purpose of converting into pig metal old iron and "suggens," that is, large lumps of scrap iron made from "boils," etc., around a blast furnace. They used an oven filled with pipes somewhat after the plan of blast furnace "iron stoves," which they heat wholly by natural gas, independent of the cupola's waste gases. The plan is reported to be of much value in assisting the cupola to run freely, and with economy of fuel over that of cold blast.

Some have tried to draw hot air from the stack of a cupola by means of a pipe leading from the stack to the fan's air entrance and then drive the air to the tuyeres as ordinarily done. This has proved a failure, owing to the hot air heating the fan and burning the belts, etc. Then, again, such a plan, the author would say, would be objectionable on the ground of the air, which was drawn from the cupola, being loaded with injurious gases or a blast less rich in oxygen than that which would come from the atmosphere or cold air. There have been what are called "jacket cupolas," designed with a view to having the blast enter at about the level of the charging door to a space of about two to four inches wide around the circumference of the whole body of the cupola before it can descend to the tuyere entrance. The principle involved in this plan is to abstract heat from the inner shell of the cupola in order to raise the temperature of the blast. There are no records to show that such a plan has proved of any real advantage in the matter of economy of fuel.

One element which is a detriment to utilizing waste gases in making warm or hot blast for cupolas in the majority of foundries at the present time is this: That many cupolas have conditions which permit their being in blast but one or two hours at a heat, thus affording very little opportunity for the waste gases to get pipes, etc., heated to a degree sufficient to raise the temperature of the blast which would pass through them, in order to do much good before it would be time for the "bottom drop." Where a cupola with one row of tuyeres must depend on its own gas to heat its blast, it would have to be running from one-half to one hour before the pipes in it or an oven could get sufficiently heated to raise the temperature of the blast to any effective degree. Many cupolas would have their heats run off by the time blast would be heated to a point to be of much benefit. The expense of keeping pipes and ovens in repair more than counterbalanced any economy which was derived from hot blast in the past, by means of a cupola's own gas or stoves heated by special firing of coal or gas to run off short heats.

Some interesting illustrations of hot blast cupolas are presented by M. Gouvy, Jr., in a work translated from the French by W. F. Durfee, M.E.* The cupola seeming to the author the most practical of those shown is that seen at Fig. 30. The plan of this cupola is to collect the metal in a crucible, B, independent of the cupola proper, and have the heat from the metal held in the crucible and gases, which would blow through the outlet E to heat up the blast pipes seen in the upper enclosure A. There is no report made of the success of this cupola, but it ought to work well.

* Presented before the Franklin Institute, 1889.

M. Gouvy, in commenting on the utility of hot blast for cupolas, says:

"Finally, we conclude that heated air for blowing cupolas only results in an increase of their melting power in consequence of the elevation of the temperature of the zone of fusion; but we do not find any economy of fuel, which fact is attributable to the zone of fusion extending to a very much greater height than when cold air is used, and therefore the carbonic acid formed at the tuyere encounters a very large surface of incandescent coke, which effects a reduction of gas, and the advantages of heating the blast are annihilated by the loss of heat due to the transformation of this carbonic acid into carbonic oxide."

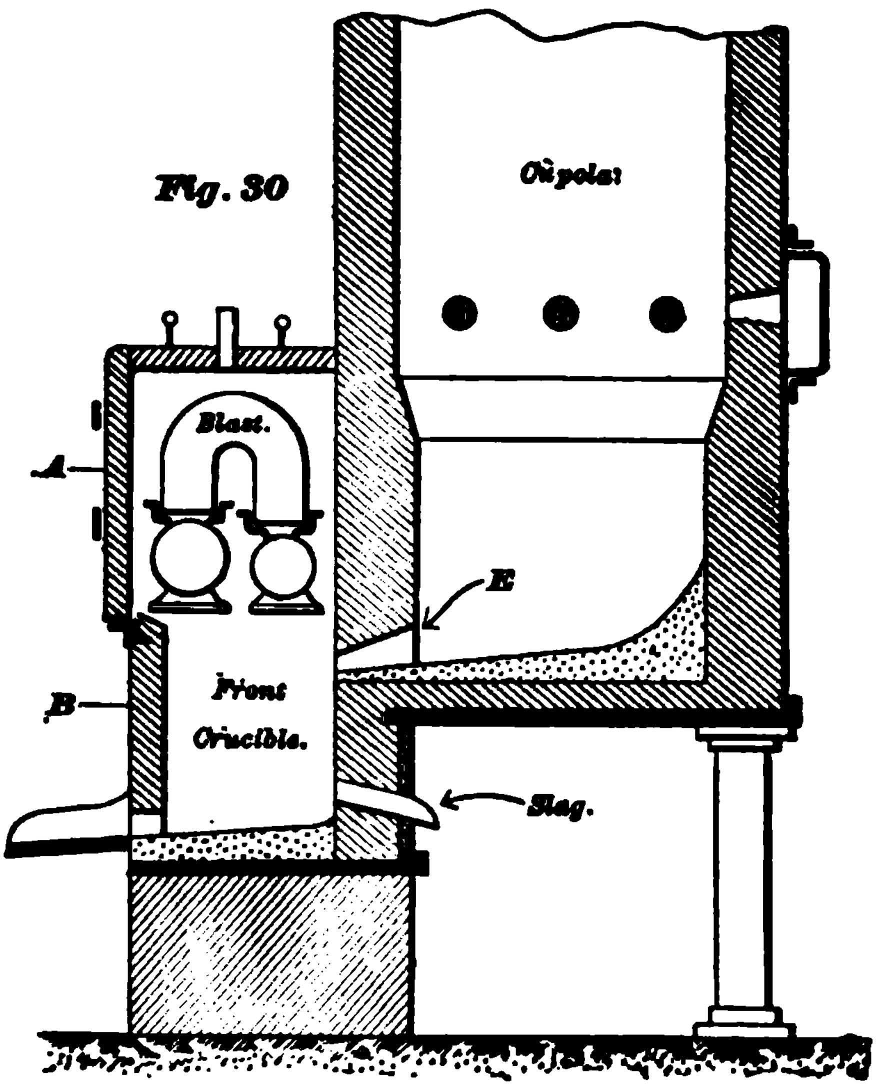


FIG. 30.—THE TITTL AND ERNDT, OR MODIFIED KRIGAR SYSTEM.

The author can not fully agree with M. Gouvy's conclusions, and would say that if we increase the melting power of a cupola, we should find economy in two ways, one of which is to permit small cupolas running larger heats than they otherwise could, and the second, by increasing speed of melting; and still again an important factor to be gained by utilizing hot blast, one which seems to have been wholly lost sight of, is that of the benefit sure to be derived in greatly preventing

tuyeres from being bridged over and finally "bunging up" a cupola to the extent which cold blast affects such action, and which, we must also remember, can often cause quite a loss in "shot iron," etc., being contaminated with the refuse of a cupola's chillings and droppings. Founders all know it is but a little while after cold blast is on a cupola that the tuyeres blacken, become dark, and the droppings of molten metal chill on the parts of coke or fuel facing the tuyeres, so that in a very short time the free entrance is greatly retarded and the bridging over and final "bunging up" of a cupola are often soon accomplished. When we know that hot blast has proven of great economy to blast furnaces and also assists them in running the long period which they do, we have every reason to believe its application to cupola practice would prove beneficial.

There is one point, however, which should be made in designing in order to make hot blast, and that is in having high cupolas. This would give the elevation of the temperature about which M. Gouvy speaks a chance to heat up a greater body of iron before it comes down to the melting point by the excessive heat created at the fusing zone in an effort to escape up the stack. It is in this quality that blast furnacemen have experienced beneficial results. Blast furnaces at one time were only about forty-eight feet high, but since the introduction of hot blast it has been found beneficial to raise furnaces to a height of 100 feet, so as to have the stock absorb all the heat possible before the escaping gases turn to pass down the "downcomer" to burn in the hot blast ovens.

Another point the author would raise is that of the benefits which might be expected in utilizing hot blast

to further advance the utility of "center-blast." By having warm or hot blast enter through a center tuyere, we would obtain the same benefits to be derived in the center tuyere being kept open to freely admit the blast, as is stated above for outside tuyeres; but if hot blast is used for a center tuyere, it would, with temperatures over 500 degrees, require some cooling arrangement similar to that shown in Chapter XVIII.

Were it not for the fact that upper tuyeres are destructive to a cupola's lining and interfere with the benefits of hot blast, the author would not advance any suggestions or plans to utilize the waste gases of a cupola, as by the use of upper tuyeres we could have little or no waste gas to utilize. Our present stage of advancement appears to offer no design that has really proved successful in economically utilizing any waste gases in order to raise the temperature of cold blast to any beneficial degree, with heats not running over two hours in duration. There is little hope of utilizing to advantage the waste gases of cupolas for short heats, but for long heats, especially in cases where "center-blast" is used, we are afforded conditions very favorable for such utilization, and in all cases where warm or hot blast can be obtained from independent sources, good results and economy in working a cupola may be expected in short as well as in long heats.

PART II.

CHAPTER XVI.

INTRODUCTION TO CUPOLA PRACTICE AND "CENTER-BLAST."

In all the different designs of cupolas and principles which have been so far tested throughout the world during the past fifty years for obtaining economy in fuel, hot iron, fast melting, saving of linings, etc., for cupolas above 46 inches inside diameter and in cupolas below 46 inches running short heats, there are none which have excelled the principle involved in "center-blast" shown in Chapters XVII. and XXI.

About the year 1889, the author conceived the idea of a "center-biast" for cupolas, but it was not until 1892 that an opportunity presented itself for him to give his ideas a practical test. When he started experimenting with "center-blast" he thought himself the first to introduce the principle, but it was found later on that one Mr. H. B Hibler had claims to the honor of being the father to the idea.* Nevertheless the author has reason to believe that he is credited by all familiar with past events with being the first to introduce what is strictly "center-blast," or a tuyere protruding directly up from the bottom, in the center portion of a cupola practical for everyday use in general founding, also the first to advance public

* See Chapter XX., page 187.

knowledge of its utility, advocate its adoption and give general information of its application to the various conditions in founding.

The all-around economy obtained by "center-blast" over past methods consists in this: 1. Greater economy of fuel. 2. Less destruction of lining. 3. Increased speed of melting. 4. Saving of labor in preparing cupolas and shoveling out refuse droppings. 5. Less wastage of chilled iron and shot. 6. Decrease of flame escaping from the stack at closing or other part of the heat. 7. Less absorption of sulphur. 8. Greater freedom for the admission of blast and less labor in keeping tuyeres open. 9. In obtaining hotter iron, or as clean iron at the closing of heats as at the beginning.

The first factor is assured by reason of there being less space for fuel in the body below the level of the "melting point," and from the fact that there is more uniform distribution of the blast throughout the body of the fuel, and again because of the tuyere openings being freer to admit the blast caused by the total volume of blast admitted being more evenly distributed with less force at all the tuyere openings, and also by the fact of the center tuyere opening being higher than the outside tuyeres, thus reducing to a greater quantity of carbonic acid the carbonic oxide formed in the lower body of the cupola.

The saving of the lining is explained by the simple fact that less force of blast or volume of carbonic acid plays against the lining, owing to its being distributed more uniformly throughout the body of the cupola.

Speed of melting is increased by reason of the greater freedom for admission of a more uniform distribu-

tion of the blast, combined with the reduced escape of carbonic oxide.

Labor is saved because of the more uniform distribution of the blast, creating less chilled material around and fronting the tuyeres, also in not burning out the cupola to such a degree as to demand large quantities of clay to be daubed on in order to patch up the badly burned out portions of the lining, and then, again, in there being less refuse to shovel out from under the cupola at every "bottom-drop."

The less wastage of chilled iron and shot is due to the higher temperature created at the closing of a "heat," largely melting away what chilled droppings may have gathered around or fronting the tuyeres during the process of a "heat," and also for the reason that the milder distribution of the blast throughout the body of the cupola does not create excessive bodies of chilled material fronting tuyeres to stick to the sides of a cupola.

Diminution of flame is due to the more thorough combustion in the melting zone, caused by the carbonic oxide evolving there more carbonic acid than at the charging door. This is so effective at the closing of a heat (if the center tuyere has been properly arranged as regards its relation in height to the outside tuyeres, about four inches above them), that all the blast force possible in cupola practice can be regulated by reason of outside and center tuyere dampers so as to cause practically little if any flame to emanate from the stack, and upon looking into a cupola the most perfect state of combustion is seen to prevail at the melting zone.

Less absorption of sulphur is due to the fact that the

more sulphur in fuel the more the iron may be expected to absorb; and it follows that the less fuel used the less the absorption of sulphur, owing to "center-blast" diminishing the ratio of fuel to iron exacted.

Greater freedom for admission of blast and less labor involved in keeping tuyere open are simply due to less chilled iron and refuse being collected in front of the tuyere openings.

Increasing the fluidity of iron as the heat advances is due to the perfection of combustion, bringing the body of fuel and walls or lining of the cupola up to a higher uniform temperature and the greater freedom from chilled material around the tuyeres during the continuation and closing of a "heat." All the above nine points will be found to place "center-blast" far in the lead of any other designs of cupolas yet introduced. The larger the cupola and longer the daily "heats," the more pronounced are the above results obtained.

The chapters following this introduction show what others think of "center-blast," illustrate their methods and describe in what manner credit is due its advancement.

"Center-blast" proper possesses the commendable characteristic of not only being well adapted to all forms of cupolas in use at the present day, but also to those that may be designed in the future to utilize natural or suction draft as well as hot blast. Any establishment having a foundry or machine shop is well fitted to construct and erect the author's "center-blast" tuyere by following the designs, details and minute descriptions which he has herein outlined. It is but just to remark he could have patented these

points, but he offers them free to the world, to the end of benefiting his fellow-craftsmen.

After perusing the following seven chapters, the reader will value a review on "center-blast," giving the author's conclusions and how "center-blast" is best used to insure success and economy in the various sizes of cupolas and conditions of founding.*

* Any who may desire more general and detailed information about past designs in cupolas, methods for working, etc., so as to possess a thorough and complete treatise on cupolas and melting iron, should combine this work with the two following volumes. The titles of chapters here appended will afford an idea of the subjects treated. As most persons interested in founding have these two works of the author, reference to the subject can be readily made:

"AMERICAN FOUNDRY PRACTICE."

"MOULDER'S TEXT-BOOK."

"MOULDER'S TEXT-BOOK"—CONTINUED.

CHAPTER XVII.

WEST'S FIRST EXPERIMENTS WITH "CENTER-BLAST." *

A brief recital of different plans and principles that have been tried in various cupolas for the past fifty years will prove very beneficial in leading up to a ready understanding of the advantages the writer desires to set forth in illustrating the new principles which he has originated in experimenting with melting by means of what we will term a "center-blast."

An investigation of the experiments made in cupolas with a view to economy in fuel shows there have been many failures, and we find almost all plans imaginable have been tried. Europe far surpasses this country in originality and novelty of designs, but I question if America has not excelled in the points of general utility. The first radical beneficial step we find to have been taken is in the adoption of the "drop-bottom," an American invention. Ere this came in use, bottoms were composed of solid masonry or fire-proof material from the ground up to the spout, and in order to get the "dump" or refuse out of the cupola after a heat was finished, the "front breast," being made large, would be knocked out and by means of pokers the ref-

* Revised extracts from a paper read by the author at the meeting of the Western Foundrymen's Association at Chicago, October 18, 1893.

use and cleanings would be raked out. I am led to believe that this plan is still being used in some parts of Europe to-day. From the adoption of the "drop-bottom" improvements have been mainly in the line of securing greater economy in the use of fuel. The most radical divergence from the common cupola has been caused by experiments in designs arranged as in the Woodward cupola, which sought to create a blast economically by means of a steam jet blowing up the stack; also, as in the Rirger cupola, which instead of forcing the blast upwards reversed the order; then, again, as in cupolas arranged to utilize gas for a fuel. In examining some of the cupolas that have been tried one would surely think that if crooks and oddity had any virtue, perfect combustion would have been accomplished long ago. This may be secured, but we find more founders have faith in the common cupola. My definition of common cupola is one of plain, cylindrical form, having one or more rows of tuyeres. The problems of inside formation and illogical shapes given to cupolas have about ran their course of absurdity, and this has been helped by late literature upon melting. We are rapidly advancing in understanding the principles and science involved in the proper construction of cupolas and melting, and to-day we find the only element of any value that has been grasped from out the chaos of ruined expectations in the construction of cupolas is that of economical combustion being attained by two or more rows of tuyeres.

The economy that is possible if two or more rows of tuyeres could only be made to force the blast to the center of the cupola and at the right elevation, caused me two or three years ago to give thought to the sub-

ject and to desire to get nearer the theoretical figure of perfect combustion (seen in Chapter XII.) than present cupolas were doing, if it could be possible.

One plan after another suggested itself until the idea of a "center-blast" came to me. Having two cupolas in our shop, I thought I would experiment with the smaller, which is 40 inches inside diameter. Cutting a round 9-inch hole in the "drop-doors," we attached to the under side, when the doors were propped up, an eight-inch blast pipe. Inside the cupola and resting on the "drop-doors" was placed a cylinder 8 inches in diameter by 18 inches in height, on the outside of which were prickers protruding about one and one-half inches, so as to support a lining of clay. On top of this cylinder was placed a clay cap supported by three pieces of fire brick so as to leave an opening two and a half inches high for the admission of the blast. The outside tuyeres were all stopped up and the blast admitted to the cupola up through this center cylinder tuyere. The astonishing feature of this experiment was the fact that there was little or no burning out of the cupola's lining. In fact, the process seemed to cause a glazing effect that was beneficial to the lining.

The experiments in this small cupola resulted so favorably in saving the lining that we concluded to try the plan in our large cupola in connection with the outside tuyeres, which we did after the plan illustrated by the cut shown at Fig. 31, page 179. Before starting in to use this bottom "center-blast" tuyere, we did not consider ourselves safe in trying to do better than one to seven or eight in fuel, as our metal came all from pig metal and had to "come down hot." With the combination of the "center-blast" and outside tuyeres, we

found we could obtain hot metal with one to ten or eleven. And I would state that the one to ten and eleven iron was often much hotter than the one to seven or eight, melted by the old process. Indeed, the iron would often come so hot that it would take considerable scrap to cool it off before it would be wise to pour the metal. To say that it would be as hot as stove moulders would often care to use it would probably be the best way to convey an idea of its heat, and it might be well to state that the metal would be hotter at the end than at the beginning of the heat.

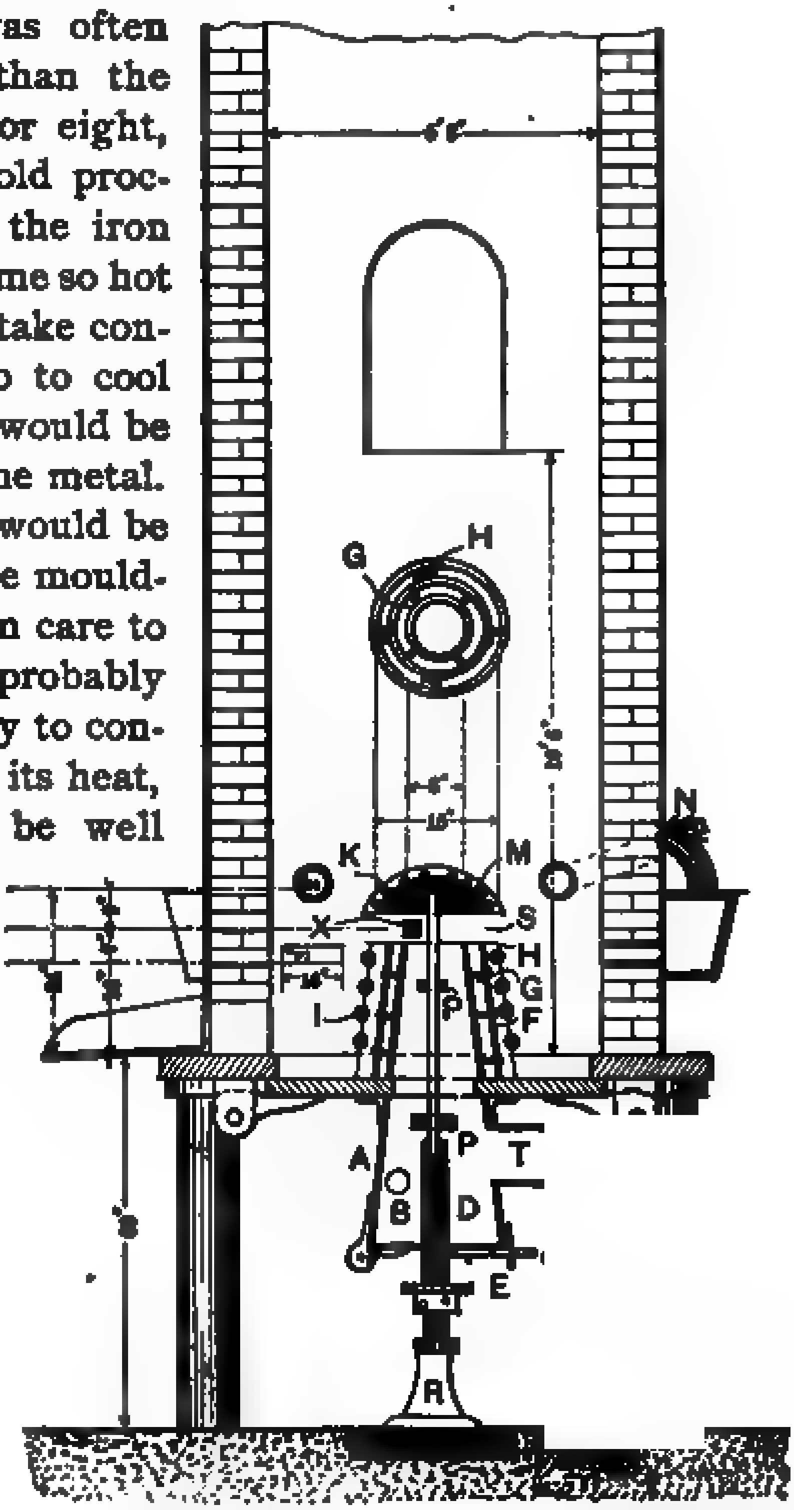


FIG. 31.—WEST'S FIRST CENTER TUYERE,

The cupola man liked to use the device, as it made the work of chipping out and

daubing up the cupola so much easier than by the old system; for, in fact, there would often be very little of such work to do.* It cannot but be evident that with such a plan the blast is conveyed to the center of the cupola or body of fuel where it should be to achieve the best results, and if the theoretical point in perfect combustion is ever to be reached, it will be done by some such system.

No doubt many can, from a glance at the drawing Fig. 31, conceive at once the whole scheme of the plan, but I think most readers would prefer a detailed description of the working of the system. A is an outside tuyere box made of one-quarter-inch wrought boiler plate, so as to make it light for dropping purposes. It is bolted only to one-half or section of the "drop-doors." B is a peep-hole, arranged with isinglass, for the purpose of seeing if all is working well. C is a hinged cover having a hole for the bar cap supporter D. At E is a one-and-one-quarter-inch hole stopped by a little pivot swinging valve, so that if through the peep-hole B any leakage should be seen, this valve could be swung back to let the metal or refuse run out. It will be noticed that the tuyere-box A is made of a taper, so that should slag iron or refuse drop down into it, it could be readily relieved. The cylinder at F is made of an inner and outer ring of one-quarter-inch boiler plate. The space G is filled with fire clay. H shows angle iron, of which there are four pieces, for the purpose of supporting the round iron rings I. These and the angle irons are for holding and preventing the sagging of the fire clay, which is daubed on over them to protect

* In my experimenting, several plans have been tried, but those seen in Chapter XXI. are the best and the author's latest.

the cylinder F from the melting heat of the cupola. How to line center tuyeres, see Chapter XXIV. K is a clay cap having a cast iron prickered casting, as shown at M. The one-and-one-half-inch bar shown at D is in two sections, so as to enable its being pulled out before "dropping the bottom."

In cases where cupolas stand high, the bar might often be worked in one piece. In placing the cap K on the cylinder, my first plan was to let it rest down upon it and then after the blast was on and the iron commenced to melt, the jackscrew R would be raised, thereby lifting, of course, the bar D and the cap K to make any width of opening at S for the admission of the blast that would be thought wise. The raising of this cap up against the pressure of coke and iron gave us trouble at one heat through breaking off of the clay at the outer rim of the cap, so that after the cast was about two-thirds over, the heat in the cupola had melted the casting M so as to cause a leakage down into the tuyere. We then tried another plan by letting the cap rest on three pieces of fire brick, one of which is seen at X, as done in the 40-inch cupola; these being equally divided, the blast would have ample room to find space for entrance between the top of the cylinder F, and the cap K, as at S. This plan was a decided improvement over raising the cap and worked all right.

The cap K, as shown, was made larger in diameter than the cylinder F, so as to prevent the dropping metal from falling or getting into the opening at S during the heat.

In making connections for the blast with the center tuyere box A, conditions will vary the plan to be

adopted. The attachable pipe coming to this tuyere and connected at T should be an independent one coming directly from the main blast pipe, and not from any of the side tuyeres or wind boxes, and a damper should be arranged in this main side branch pipe so that the pressure of the "center-blast" can be regulated independent of the outside blast. The cupola shown has twelve outside tuyeres, six of them being lower tuyeres, 3x16 inches, and six of them upper tuyeres, two inches in diameter. The width of opening for the "center-blast" admitting of air at S was about two and one-half inches. The blast should not pass through the center tuyere with any more force than necessary to counterbalance the outside wind pressure, unless "cloggings" are desired to be melted away from around either tuyere, in which case the blast pressure should be decreased in the tuyere or tuyeres to be freed of "cloggings." This is one of the advantages obtained by combining center and outside tuyeres, as by decreasing the blast in one, the pressure of the other can drive a fusing flame of carbon and hot blast through the chilled material to soon melt it away, and hence open up what was a "bunged" tuyere. Alternating the blast pressures from center to outside will be very effective in keeping all the tuyeres open, and is a practice very essential to long "heats" in small cupolas using "center-blast." See pages 194 and 215. The blast we use is delivered from a No. 9 Sturtevant fan.

CHAPTER XVIII.

STOTT'S "CENTER-BLAST" CUPOLA.

The following description of Stott's "Center-Blast" Cupola originally appeared in *The Foundry*, July 10, 1894:

The one we illustrate here at Fig. 32 is known as Stott's Improved Cupola, and is very similar in some respects to the cupola introduced and described by Thomas D. West some little time ago. Mr. Stott declares he first tried this plan in Thibodeaux, La., in the year 1888, and has since erected several successfully. His methods incorporating one or two original ideas that he says work successfully, we have given it space for the benefit of our readers.

In our illustration, A A A illustrates the blast pipe leading below and up into the center of cupola. J represents water pipes which pass into and upwards through center of blast pipe, the latter being covered with fire clay or other fire proof material to protect it from heat of fuel, and melted metals. B B are the drop doors so arranged and shaped as to admit of the introduction of blast pipe A. C, the tap hole, D D the apertures for blast, E, hollow iron cone covered like A to protect from heat and filled with running water, and which serves to protect interior of pipe A from receiving fuel or melted iron. It rests on three iron sockets which set into pipe A.

There is a joint in pipe A, marked F, which is secured when pipe is in position by clamps. In the bottom of pipe A is a hinged bottom that may be opened and closed at will for purposes of cleaning, and which has a hole filled with lead that will melt out in case pipe gets any melted iron in it. H is a stand for bottom of blast pipe and has a flange at top which enables the sliding of blast pipe A forward or backward, as may be required before

FIG. 32.—STOTT'S IMPROVED CUPOLA.

and after casting. I is water tank for holding water to feed cone E. While casting, this water passes from tank through pipe K down to pipe J and up into cone, from which it escapes into the overflow pipe and goes out by way of L and M.

The method of operating is about as follows: Put in place doors B B and put in blast pipe through charging doors, when it will rest on flanges at O, then put cone E in place, screw water pipes J into bottom of cone E and screw them into the elbows of pipes, extending through blast pipe A at L, L, also union coupling at M, M; then make up sand bottom on doors, above blast pipe A2 into position and clamp flanges together. When heat is finished, pull back blast pipe where it slides on stand H, unscrew sections L M, drop doors, and blast pipe and cone will drop.

It is asserted that a cupola built and operated in this manner

is in successful operation and that another and much larger one is in process of construction.

Stott's plan of "center-blast" agrees very closely with that of the author. It differs mainly in his inserting pipes through which water may run to keep the center tuyere cool, a principle which for cupolas running a week at a stretch, as in steel work practice, might prove very desirable. The plan which Mr. Stott shows at A for removing the bottom blast connections rapidly, if necessary, is very good and is an arrangement which should be provided in some form or other in all "center-blast" cupolas, as can be seen by referring to Chapter XXI., page 198.

CHAPTER XIX.

CALDWELL'S "CENTER-BLAST" CUPOLA EXPERIMENTS.

The following article was printed in *The Foundry*, February, 1894:

A few years ago I made the experiment precisely in the same way as described by Mr. West in the November number of *The Foundry*, in a small foundry in Brockport, N. Y., in the full belief that I was the first and only person who had ever tried such a plan. It gave entire satisfaction; indeed, it exceeded my expectation, as I found I could melt faster and hotter with less fuel than any way I ever saw tried before, and that is the result all foundrymen are looking for. If some of the leading men in the business would give it a trial, they would see the advantages it has over all other known methods, and its adoption would become common in a short time among the foundries, for it will not only save time and fuel, but will save the lining, which is a large item.

I have been engaged in connection with the foundry business for many years and have closely watched the many attempts made to cheapen and facilitate the melting of iron, and I feel quite safe to say that the bottom center tuyere is the correct way of applying the blast to a circular cupola. Besides, a cupola can be built much cheaper, as it need not be so high above the foundry floor; nor the stack built up to the skies to keep the coal from blowing out at the top. Iron can be melted in an old hogshead without any stack at all (though not quite so safely, perhaps,) as in a hundred-dollar furnace. I have been trying to find an opportunity to try my plan in a large cupola, as the larger the better, and hope to do so soon.

LANCASTER, Erie Co., N. Y., Feb., 1894.

CHAPTER XX.

HIBLER'S AND JOHNSON'S PATENT "CENTER-BLAST" CUPOLAS.

The following letter is taken from the *American Machinist:*

In your Nov. 30th issue, Mr. West's article I appreciate, also article you kindly published entitled "Remarkable Coincidence," but take exception to the title of the latter. I take pleasure in sending you Mr. B. H. Hibler's patent papers, which I obtained from Mr. Stewart, patent solicitor here. You will notice from the drawing (Fig. 33) that it is entirely unlike the West central tuyere, as printed in Nov. 3d issue. This patent being granted Aug. 13, 1867, it is but fair to admit that Mr. Hibler invented the first central blast tuyere; if it had been a success, would not the enterprising cupola builders have

FIG. 33.—HIBLER'S PAT. "CENTER-BLAST."

adopted it? Would it have been hidden under a bushel for 26 years? Mr. West's central blast is entirely different in mechanical construction, as you will notice in comparing drawings, and looks to me like a great improvement on Mr. Hibler's. You can patent a windmill but you cannot patent the wind, as you have said in the *American Machinist* long ago. The 'coincidence' of the central blast question we notice, but compare the drawings and you see nothing 'remarkable' except being so different in design.

READING, Pa., Dec. 28, 1893. T. BEVERLEY KEIM.

FIG. 34.—JOHNSON'S PATENT "CENTER-BLAST" CUPOLA.

Johnson's patent "center-blast" cupola. In the above, Fig. 34, is shown a design of "center-blast" patented by Mr. Charles Johnson, of Rutland, Vt., June 25, 1895; number of patent, 541,759. The patent was

applied for on December 1, 1894. This patent is at present being handled by a foundry outfitting company, which, it is claimed, is erecting quite a number in different parts of the country. Mr. Johnson's plan of having an upper opening, as shown, should have the same effect as upper tuyeres in the outer circle of a cupola to assist more perfect combustion, and should prove very beneficial where the top cap is not being carried up too high to endanger its being ruptured by the descending stock or the excessive heat of the "melting point."

CHAPTER XXI.

POWER OF BLAST PENETRATION AND IMPROVEMENTS IN "CENTER-BLAST."*

There has been much speculation as to the force of blast existing in the center body of a cupola. Some have gone so far as to assert that the burning out of a cupola's lining at the melting point was due to the force of blast from the opposite tuyeres. The conviction that blast expends its power most largely at the entrance of a tuyere has been an incentive to the writer to utilize "center-blast," and the economical results which he has obtained from its use have demonstrated to him that his convictions on this point are correct. A little experiment which the writer conducted recently will show any one trying it in large cupolas the inability of blast to exert any great power or pressure in the center body of the cupola. This experiment consists in simply getting into the inside of a cupola after the bottom is put up and holding a handkerchief at varying distances from the outside tuyere openings, with the blast or fan running at full speed. In the 66-inch cupola shown in Fig. 40, having six tuyeres 3x16 inches, holding the handkerchief a foot away from the tuyere opening or inside surface of the cupola, the blast had no perceptible influence on it. This

* Revised extract of paper read before the Western Foundrymen's Association, Chicago, June 17, 1896.

was a revelation to the writer, as he thought before entering the cupola that he would be smothered with the effects of rushing air, but was happily disappointed. Of course, the writer does not wish to imply by this that when a cupola is filled with fuel and iron, the blast will not penetrate further toward the center; but nevertheless, it is very far from exerting the same pressure, or giving the same volume, at the center as it does at the outside entrance.

FIG. 37.—WEST'S IMPROVED "CENTER-BLAST" FOR SMALL CUPOLAS.

To more fully prove this, it is but necessary to watch a cupola at the close of its heat, when the stock is settled down, say, about half way, so as to enable one to observe more directly the action of the blast. Here a careful observer will readily notice that the action of the blast is to turn upward right at the tuyere's entrance with but a very small percentage of the blast reaching the central body. In fact, the blast

at the tuyere entrance creates such excessive combustion at the outer circle that very hot flames will be seen burning upward right over the tuyeres, playing against the walls or lining of the cupola, with the center body of the cupola comparatively free from live combustion. We may, by reason of greater blast pressure, or a smaller tuyere area at its entrance to the cupola, penetrate the center body of the fuel in a cupola to a much greater extent than can be obtained with the ordinary pressure used. Blast furnace practice demonstrates to us what high pressures can do to force blast to the center, but we find such a practice in cupola work to be very objectionable, simply on the ground that small tuyere area or high pressures of cold blast cause rapid chilling or closing up of the blast passage at the front of tuyeres. For this reason we find high pressures or small tuyere areas, especially where coke is used, very objectionable in cupola practice, because of the cold blast. If any one will conduct the experiment cited above, of getting into a cupola to test with a handkerchief the extent of blast penetration, the author believes he will be brought to realize more than ever the utility of "center-blast" for cupola practice.

Ever since the writer first introduced "center-blast" proper in his paper before this association, in October, 1893, he has been continually experimenting to further improve and perfect "center-blast," with the idea of making it so simple and reliable that all founders would find it to their advantage to adopt such methods.

The objection to "center-blast," at the time of its introduction by the writer, was due to the difficulty of

erecting same and connecting to blast attachments. By a study of this paper, those two objections will be found largely removed. In Fig. 40, page 195, is seen an arrangement designed by the writer, whereby the center tuyere is a permanent fixture, not requiring to be dropped with the bottom at the close of a heat, as is necessary with all other designs. This is only practical with cupolas over 50 inches inside diameter. For cupolas below this size the author has designed the improvement seen in Fig. 37, page 191. The advantage of this construction lies in the "drop door" being so designed that it obviates the necessity of putting up and taking down blast pipe connections every "heat." It will be understood that in cupolas below 50 inches it is intended the center tuyere shall drop with the bottom at the close of a "heat." The

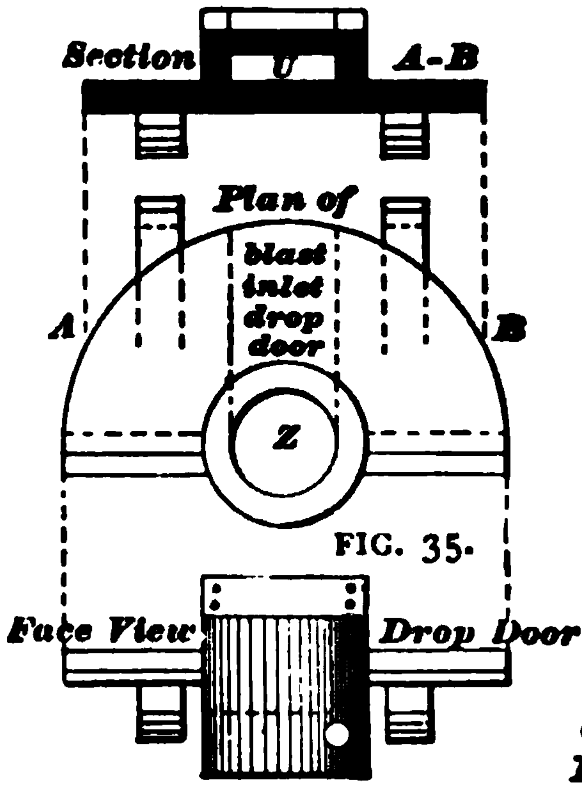


FIG. 35.

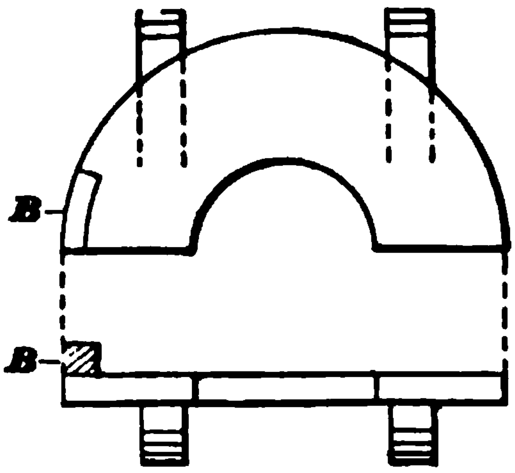


FIG. 36.—PLAN OF PLAIN HALF DROP DOOR.

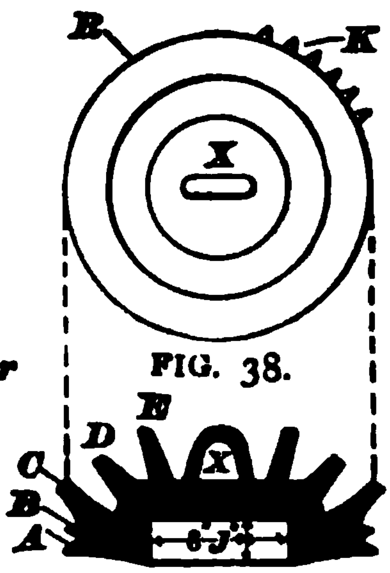


FIG. 38.

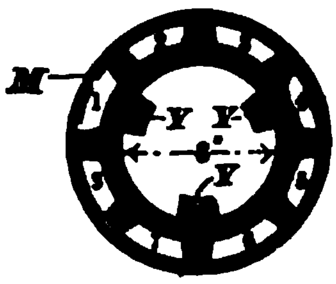


FIG. 39.

writer has not, as yet, used the principle seen in the blast inlet drop door shown in Fig. 37, but from his experience he knows that if the plan shown is followed, it will prove quite a convenience over other methods now being advanced.

As will be seen, the writer advises the use of outside tuyeres in connection with the center tuyere, providing they are made independent of each other in action, by reason of valves or blast gates, as seen in Fig. 37, whereby the blast pressure can be perfectly controlled in the center and outside tuyeres to obtain whatever pressure in either may be thought best. See page 182.

The blast area of the opening at U, Figs. 37 and 35, is to be found by dividing the area of the cupola by 30. If the cupola is 40 inches inside diameter, this gives an area of 41.89 inches, or, in rough figures, an opening 4x10 inches, and at I a diameter of about 7 inches. This rule can also be applied to find the mean diameter of the opening at M and I, Fig. 40, for all center tuyeres, which for a 30-inch cupola gives an opening of about 5½ inches diameter; for a 50-inch cupola about 9 inches; for a 60-inch cupola about 11 inches, and for a 70-inch cupola about 12½ inches opening. This is to be understood as the mean diameters; and as the tuyeres are tapering, the top at I is intended to be two inches less in diameter than the bottom at M, thus making the opening at I about 4½, 6, 8, 10, and 11½ inches, respectively, for the diameters of cupolas described. The width of the opening at V for the admission of the blast to the stock in the cupola should range from 2½ to three inches, the larger space being best applicable for long heats.

It will be noticed that the drop door, page 191,

calls for a greater height of bottom sand by two to three inches than is usually adopted in the ordinary cupola. This may be objectionable for small cupolas, but the same can be overcome by having the drop doors extend lower with a flange around the circumference to project upward to close the bottom plate of the cupola, as suggested at B B, Fig. 36, page 193, and cutting a piece out of the bottom plate at B, Fig. 37, page 191, and then strengthening the same with a wrought sheet bolted to the bottom plate. For holding up the drop doors with props, two bars are to be used as represented at E, Fig. 37, one to be on each side of the blast inlet circle. H is a door so hinged and held up by means of the weight, wire rope, hook and staple seen at M, P and F, that should any occasion call for its being opened suddenly to release any slag or molten metal that might, from any cause, leak

FIG. 40.—WEST'S PERMANENT STANDING "CENTER-BLAST" FOR LARGE CUPOLAS.

down the center tuyere, it can be quickly operated without causing any stoppage or much loss in blast. S is a peep-hole to be closed with isinglass. A is a rib to make a backing for clay to tightly close the joint of the drop door in its union with the wind box K, and which should be of the same area at A for the admission of blast as that cited for the area at U. D is a recess to admit a slide valve to close the end of the wind box K. N is one of the ear-lugs for hinging the drop doors. R is the sand bottom showing the cupola ready for its bed of fuel. C, the center tuyere, and X the covering cap. W, branch pipe for the outside tuyeres, and L for the center. The plan and section views of the drop doors seen at Figs. 35 and 36, page 193, will explain themselves.

In describing the large cupola, Fig. 40, the cap casting seen at Fig. 38 should not be less than one and one-quarter inch thick in any part, and the greatest attention paid to having the edge at R closely pricked with a double row of one-quarter inch pieces of wrought iron rods or nails, as suggested at K and A B, Fig. 38. The cap X is the only part of the tuyere requiring extra care. This is necessary in order to get it to stand the action of the fusing heat and friction of the steady downward movement of the fuel and iron when the cupola is in blast. Protect the edge R so that the clay cannot be broken away from it, and you can then expect perfect success in utilizing "center-blast." The prickers C, D and E should extend about two inches high and be as thick as they can be comfortably cast on. X at Fig. 38 is a one-half-inch hook cast in the cap to handle it by. The recess at J should be about three inches deep and of a diameter to admit the cap

supporters, as seen at Y Y Y, Fig. 39. Where cupolas are to be run over four hours it is well to have four of these supporters instead of the three shown. These supporters are made of one-and-one-quarter-inch wrought iron bolted to the tuyere casting. It is not necessary to protect them by clay, likewise under the side of the cap at E, Fig. 40, as the cold blast keeps these points sufficiently cool to prevent them fusing or even getting very hot.

This cap should be about four inches larger in diameter over all than the outside of the center tuyere up at V. The center tuyere upright is made of cast iron. In the plan view at Fig. 39 are seen eight ribs cast so as to run the entire length of the tuyere, over which are placed one-half-inch wrought iron rings, as seen at M, Fig. 39, and at the numerals, 1, 2, 3, 4, 5 and 6, Fig. 40. Owing to the center tuyere being made on a taper, as shown, these rings are readily adjusted to tighten themselves. We find this method better than prickers to hold the clay and to extend the life of a tuyere to run through a large number of "heats." A quarter-inch wrought iron or boiler plate upright tuyere could be used in place of the cast iron one shown, which is about three-quarters of an inch thick, and for cupolas where it was intended to drop them with the bottom, boiler plate center tuyeres would be best on account of their being lighter to handle. These upright tuyeres and covering caps are dried in their positions or in an oven before being subjected to a regular "heat," as explained page 213.

It is to be understood that the tuyere shown with the large cupola or Fig. 40 is a permanent structure, not to be dropped with the bottom, thereby overcom-

ing the inconvenience heretofore experienced in being compelled to erect a center tuyere at every "heat."

The recess at N, Fig. 40, is caused by reason of making that part of the diameter sufficiently large to admit of the door dropping without striking the flange through the section O O. A flange will be noticed on the center tuyere at its lower body, projecting over the drop doors. This is needed in case it might, at any time, be found necessary during a heat to move the section M. This section is seen to have one end on an incline as at the flange A and B, and on removal of the pins H H can be readily slid out from under the center tuyere, after the branch blast pipe attached to T is disconnected. In a few moments the section M can be replaced ready again for the passage of blast. At F is shown an opening level with the ground floor, at which point is also seen a door, U, which should extend fully half the way round the column, as shown, and have double doors, so that should any iron or slag for any reason chill inside of the column at its bottom it can be readily removed. The slope D at this door inside the column is formed of sand. If rough castings are used, the points at A B and O O can be bedded in soft clay to make them wind-tight. Of course these joints could be planed to save this labor, if desired.

The writer has not shown any outside blast connection or branch pipes to lead to the center tuyere projection T, Fig. 40, for the reason that there are but very few cupolas alike in their wind box and blast connections.

When first starting to use "center-blast," the author thought he would have difficulty in obtaining a

lining for the tuyere and covering cap that would withstand the fusing heat of the cupola. Experience has proved that any fair grade of fire clay will answer, and while it is advisable to have an extra dried tuyere and covering cap on hand, many will be surprised to learn that where center tuyeres are not dropped with the bottom, they will run for three dozen or more "heats," or as long as they are kept repaired with clay.

Every now and then we hear of somebody resurrecting old designs, thinking they have something new. The author has now special reference to the plan being advocated of drawing in a cupola above the tuyeres, making its area at the bosh thus formed, about a third less than any other part of the cupola, thinking by this to attain the end gained by "center-blast." The bunging up due to such designs, where the heats are extended to any length, long since has relegated this old design to obscurity. The writer has tried all these methods to learn just how far they could be utilized in an effort to approach "center-blast," but has found them of little value in obtaining the benefits to be derived from "center-blast" proper. See page 201.

The arrangement of the designs for "center-blast" herein described admits of a cupola being run to finish its "heat" should anything go wrong with the center tuyere. The removal of the section M, Fig. 40, or the opening of the drop door H, Fig. 37, admits of the center tuyere proper being plugged up with stiff clay, so as to shut its blast off, and permits a continuation of a heat by the use of the outside tuyere.

The arrangement shown in Fig. 40 has been long used in our foundry with the greatest success, not only in "heats" of an hour or two, but in "heats"

of four to six hours, since we seldom melt less than forty or fifty tons at a "heat," in the large cupola shown. It will thus be seen the center tuyere has been subjected to a very rigid test.

The iron we melt is mostly all pig, only shop scrap being mixed in with it, and the mixture we use must not exceed .10 in phosphorus, which calls for a greater percentage in fuel than if the phosphorus was higher, owing to the greater fluidity which an increase of phosphorus can add to the metal. The ratio of fuel used with this tuyere ranges from 1 to 11 to 1 to 13, in heats running from 40 to 70 tons. These ratios are to be understood as including the coke used for the "bed," as well as that used between all the charges of iron. The ratios were figured from the actual weight of the fuel and iron used in these cases as they came in cars and buggies to our yard or cupola staging. This economy of fuel, it is to be remembered, is achieved in a cupola that, having the same conditions in fuels, flux, iron and blast, etc., cannot do better than about 1 to 9, when only the outside tuyeres are used.

CHAPTER XXII.

EXPERIMENTS APPROACHING "CENTER-BLAST."

In order to advance practice on contracted cupolas to compare with "center-blast" proper, the author concluded to give his attention to the formation of a cupola's lining, as seen in Figs. 41 and 42. The first experiment which the author tried in this direction was to bring in the lining all around the cupola over the tuyeres about as shown at M, Fig. 42, page 203. This plan showed some improvement, with this big cupola, in the matter of economy in fuel, and saving of lining over that of having strictly a straight-lined cupola. But feeling that a nearer approach to the center with a forcible blast would further increase the utility of the above two points, he remodeled the shape of the lining after the plan illustrated in Fig. 41. This plan he continued using for about six months, attaining results comparing partially with the "bottom-center tuyere," shown in Chapter XVII.

By an examination of the plan, which shows a section through A B, there will be seen two projections extending out 18 inches from the inner surface of the lining, the one on the side at A standing higher than on the side B. The side A, or projection H, was carried up higher for the purpose of having an upper tuyere

D to aid in reaching the center with a blast to blend with that blown in at the tuyeres E and F, in order to attain the ends sought by "upper tuyeres" as generally used. The objection he found to this plan was the repairs necessary at every "heat" to keep the point at H in right form, owing to its being so close to the "melting point." The lower tuyere of the projection K called for but little repair, as at the end of six months' running of three heats per week it showed but little wear. Some might think that bringing in a cupola so radically, as illustrated in this case, would have a tendency to "bung up" a cupola. I would say that we found no difficulty on this score with our weight of heats in this large cupola, and to explain why it might be well to discuss the logic of the practice followed. In this formation it will be seen that the area at the height of the lower tuyeres gave a form of 28 x 56 inches, which when taken into

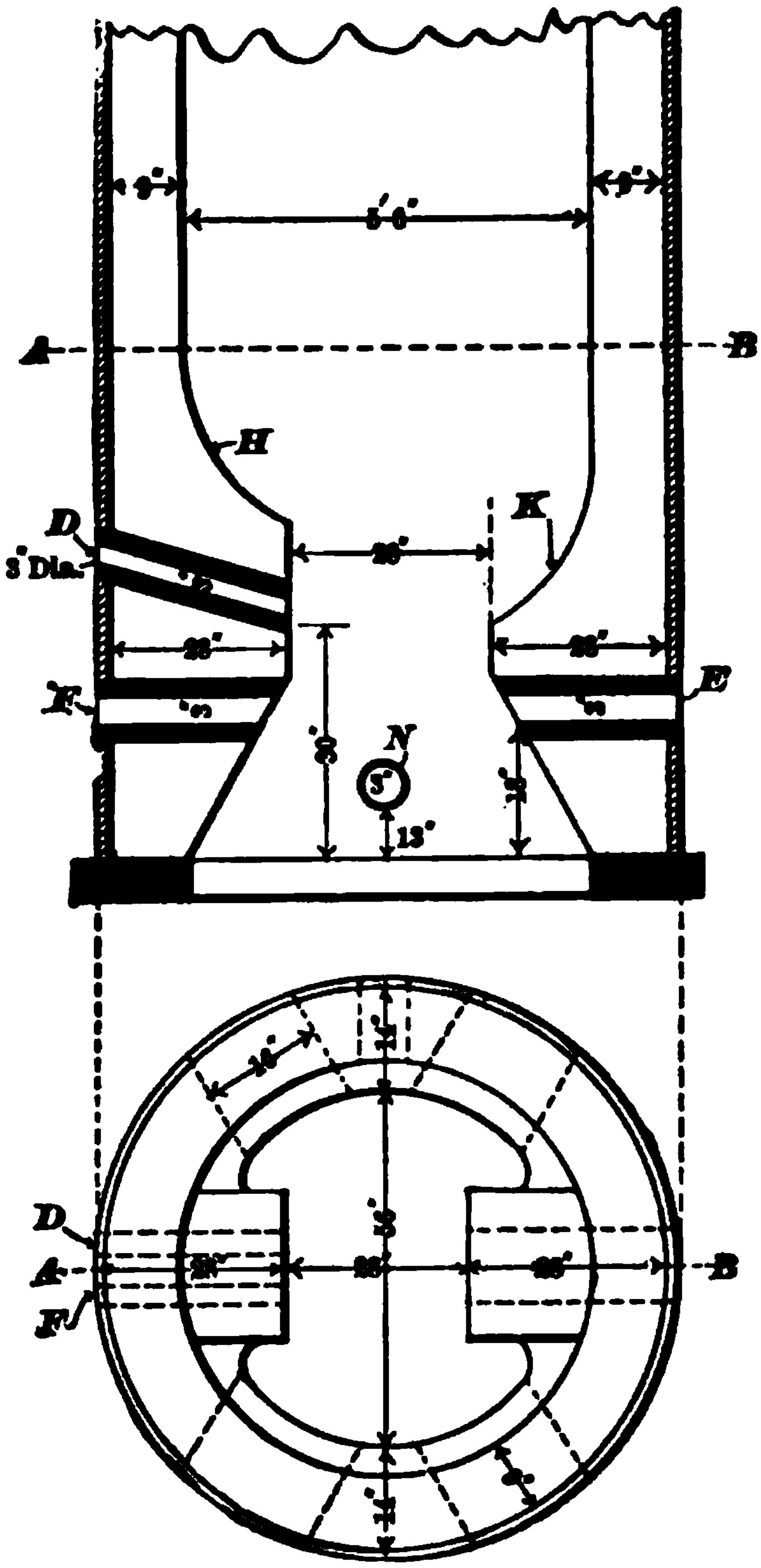


FIG. 41.

consideration left an area in proportion to that above the projection K and M, ample to insure successful working as long as the cupola was "slagged out" properly.

After using the projection H or the upper tuyere D for a few months, we fell back to the section shown at B, page 343, and experimented as to how far it was advisable to carry this projection forward toward the center. In the cut B referred to, we had a projection all around the cupola so that the diameter at the point shown at M in Fig. 42 measured about fifty-eight inches. After another period we remodeled the tuyere portion and worked with the cupola lined as shown at M, Fig. 42, and plan section of same through O P. To find by trial how far it

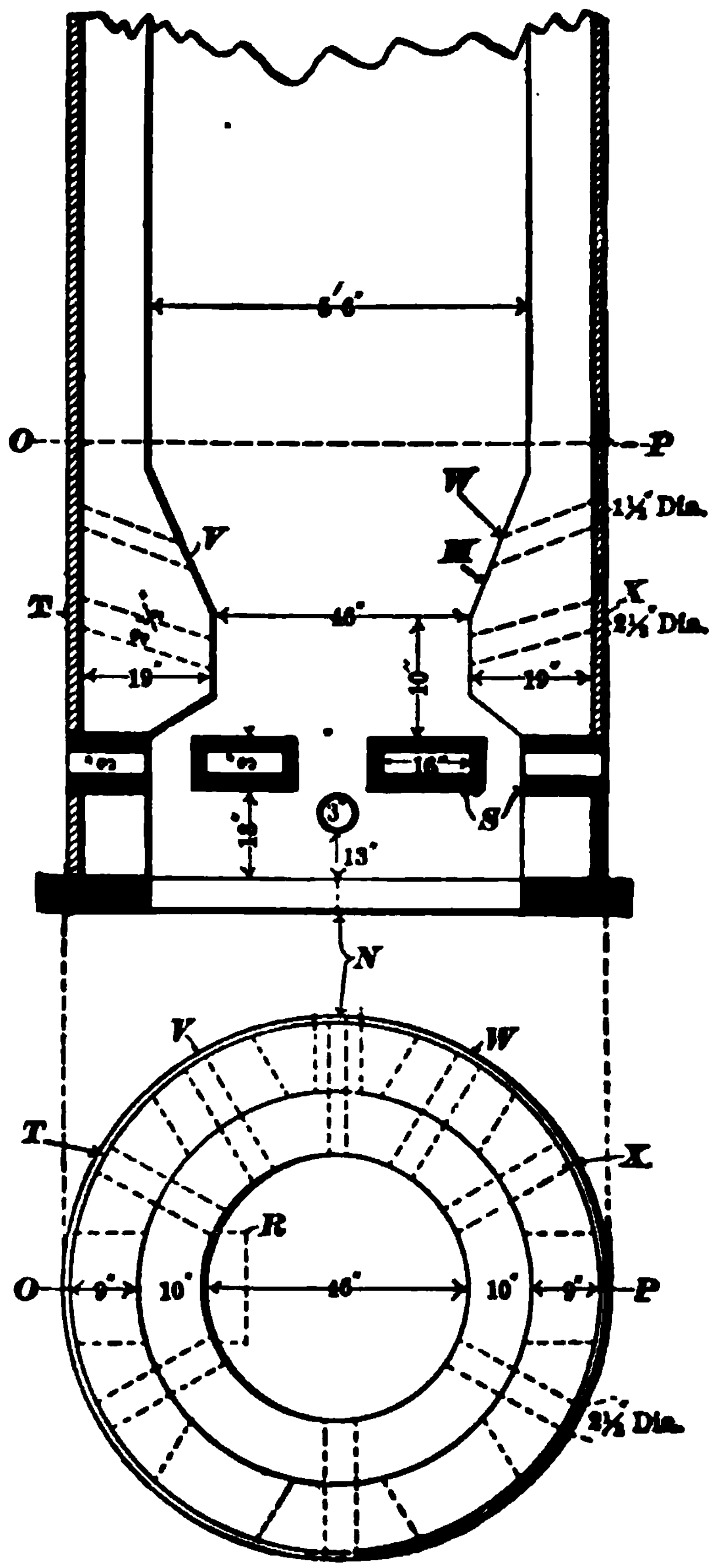


FIG. 42.

was practical with our weights of "heats" to extend the lining in over the tuyeres, as described in Fig. 42,

we did not abandon using the projection K, Fig. 41, but used it in connection with the plan as shown by the dotted line at R seen in the plan view of Fig. 42.

The idea of contracting a cupola at or above the tuyeres cannot be said to be new, for we find similar suggestions in the profiles of the "Gerhardi cupola," the "Ireland cupola," the "Woodward cupola," the "Herbertz cupola" and the "McKenzie cupola," all of which have been used for many years. The Herbertz and McKenzie cupolas come nearer in design to the principles here outlined in Fig. 42, but the plan of running out projections, as illustrated at H and K, Fig. 41, is entirely original with the author as far as his knowledge goes, and he can say it has been effective in achieving desirable results for large cupolas. The objections to the "Ireland," the "Gerhardi" and the "Woodward" cupolas are that their lower tuyeres, instead of being below the crown or projection M, as at S, Fig. 42, are all upon a level with the smallest diameter of the cupola's area, somewhat after the idea shown in Fig. 51, Chapter XXVIII., page 235, thereby making conditions much more favorable for causing a cupola to "bung up" or bridge over right at, or above, the tuyeres.

We tried bringing the cupola in still less than 46 inches over the tuyeres, as seen in Fig. 42, but cannot say that the results were satisfactory, and concluded we had reached the limit in the 46 inches shown at Fig. 42, and even with this diameter, the longer it was used the less we were satisfied with the results. We accordingly remodeled the cupola back to the form seen in Fig. 41, as with this plan, excepting the "bottom center-blast tuyere" shown in Chapters XVII. and

XXI., page 195, we have obtained better all-around melting results than with any other principle which we have used for melting in large cupolas.

The objection we found to plan Fig. 42 is, that after about twenty tons are melted, it commences to rapidly clog between the top of the tuyeres and the under side of the projection, thereby retarding melting, and in the morning there is a combined clog of coke, iron and slag all around the cupola under the shoulders projecting over the tuyeres, causing not only a loss of iron, but making extra labor for cleaning out and getting the cupola ready. For twenty-ton "heats" such a plan will work fairly well in a cupola of about this size, but for larger "heats" the plan shown in Fig. 41 is much preferable in standing next to advantages of "center-blast" proper.

CHAPTER XXIII.

NEW SIDE "CENTER-BLAST" TUYERE.

In the accompanying cut (Fig. 43) is illustrated another plan the author has designed for obtaining "side center-blast" to save lining, etc. As there are so many different designs of wind boxes, or tuyere pipes, carrying the blast to cupola tuyeres, I offer no advice for attaching wind connection to the sliding pipe X, but that is of secondary importance; a little inventive talent would soon arrange for that. The plan presented is simply to have two tapering pipes, as seen at X and K, the taper to be about one inch in two feet, the latter having

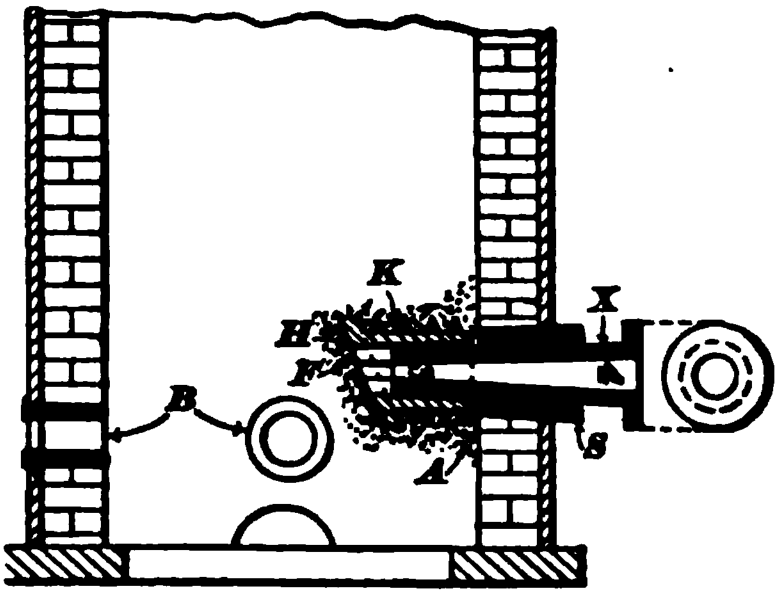


FIG. 43.

"prickers" cast on for holding a clay or refractory lining as shown, and when preparing the cupola insert X into the fixed sleeve S and place K on over it; then stop or close up the joint between the walls of the cupola and K, as seen at A, also close the inner joint as shown at F; and then, before "dropping the bottom," pull back X so as to cut free or clear of K and thus leave the latter free to drop with the

bottom. Should it not come down, a little prying on it through the opening S with a bar should cause it to drop. For a 30-inch cupola I would advise the use of three protruding tuyeres, for a 40-inch cupola four tuyeres and for a 60-inch six tuyeres, all to be four inches diameter at the smallest point of admittance of the blast to the cupola. The protruding tuyeres should not come together to the center by about two feet; in any case and for cupolas over 50 inches, outside tuyeres, as seen at B, can be used in connection with the protruding tuyeres shown.

The foundryman cannot expect as even a distribution of the blast or the economical results in saving linings, etc., by the plan here presented for large cupolas as by the bottom "center tuyere" shown in Chapters XVII. and XXI., but it offers a good chance to get at the tuyeres to keep them free and open, and can be readily attached to the cupolas, and for cupolas under fifty inches inside diameter may be often found of an advantage where trouble for any reason is experienced with rapid burning out of the lining. In using the protruding tuyeres here shown, it would be essential to have two or three sets of K castings kept on hand, so that they could be daubed and dried and ready for use, as it would not do to attempt to daub them when in their position in the cupolas. The slanting face of K, as shown at H, is for the purpose of preventing the falling metal from running into the tuyeres. This plan of a tuyere approaches that found so essential for blast furnace work. It is in blast furnaces that the utility of having the blast forced to the center is thoroughly demonstrated. Often in furnace smelting it is found necessary to crowd the tuyeres in further tow-

ard the center than they are ordinarily placed, to cause the combustion and good working that should exist uniformly throughout the furnace. The desirable results obtained by the protrusion of tuyeres in the blast furnace is another element showing the founder the benefits which he may in many cases expect by the adoption of "center-blast," etc., in cupola work.

CHAPTER XXIV.

GENERAL APPLICATION OF AND INSTRUCTIONS FOR UTILIZING "CENTER-BLAST."

The larger the cupola and the longer the daily "heats," the better the all-around economy to be derived from the adoption of "center-blast." In cupolas under 40 inches inside measure, there is not the economy in fuel or speed in melting to be expected that can be attained in larger cupolas. The main economy with "center-blast" in small cupolas, over past methods of outside tuyeres only, lies in the saving of the lining and for "heats" not exceeding one and a half hours duration, works well, but longer than this, it is not recommended for small cupolas, owing to the liability of the center tuyere bunging up where cold blast is used. For the area of center tuyeres to conform with the diameter of cupolas, see page 194. It requires a little experience to utilize "center-blast" to the best economy. But when a cupola man learns to operate "center-blast," he will be the first to object to its being taken away, especially in large cupolas running long heats, for the reason that it saves him much labor in picking out his cupola and has less droppings to shovel out, and repairs to make in daubing up the cupola. Then again, when the cupola is in blast, he

finds little or no labor necessary to keep his tuyeres open, as it is remarkable what a difference exists in having free tuyeres as against the practice of not including "center-blast."

Another point well to bear in mind is the fact that the less fuel used in a cupola the less ash or slag to be gotten rid of or to cause a cupola to "bung up;" as "center-blast" requires less fuel than any other method, it will be readily seen that such practice keeps the creation of slag and dirt in a cupola down to a minimum. In starting in to try "center-blast," one is not expected at the very first heat to charge with a radical change in decreasing the fuel, but gradually trying less every heat until he finds by trial just how low he can get. At the start the foundrymen can at least depend on reducing the "bed" in bulk whatever the bulk of his center tuyere may occupy in all cupolas and between charges have fifteen per cent. less fuel in all cupolas over 40 inches, and five to ten per cent. less in all under 40 inches diameter. A poorer grade of fuel can be utilized with "center-blast" than with outside tuyeres alone.

There is nothing in the construction and erection of "center-blast" for practical application that should cause any founder to hesitate in adopting it, or that should prevent his making all the appliances in his shop, excepting sheet iron blast pipe connections, which any tinsmith can construct for him. It is always well to combine outside tuyeres with the "center-blast" so arranged with dampers that both can be used together or independently of each other, as seen in Fig. 37, Chapter XXI. It must be remembered that in all cases, the more blast passing through the center

tuyere in preference to the outside tuyeres, the less the lining will be cut out. In cupolas over 50 inches inside diameter, it will be found most economical in fuel and speed of melting to have the outside blast about equal in pressure to the center to whatever degree the fan can drive it through the entire opening of the dampers in both connections and for smaller cupolas, to have the greater volume pass through the center tuyere. A large cupola will stand harder driving to force fast melting, where the center and outside tuyeres are used in connection, than where either are only used. The larger the cupola, the more pronounced are the benefits in this line. In cases where slow melting might be desired, or small "heats" made, "center-blast" can be used independently of the outside, and such practice will still further lessen the burning out of the lining. Wherever the outside and center tuyeres are combined, the opening of the center tuyere admitting blast to the fuel should be carried up to a height of from three to six inches above the level of the outside tuyeres. One object of this is to carry the center opening well up out of the reach of any slag that might accumulate in a cupola to aid in "bunging up" the blast entrance, and again, owing to the fact that the center tuyere being higher than the outside tuyeres, achieves the end designed to be accomplished by the use of outside "upper tuyeres," namely: to aid more perfect combustion, as discussed in Chapters XII. and XVII., pages 138 and 177, also illustrated in the Voisin or Colliau cupolas.

If the center tuyere is used alone, as is practical in small cupolas running heats of about one hour's dura-

tion, it need not project above the level of that found best for economy of fuel with outside tuyeres, as by this arrangement less fuel can be used for the bed; but it must be remembered that this is not recommended for small cupolas that may be taxed to run long "heats"; in fact, "center-blast" is not recommended where long heats are to be run in small cupolas below 40 inches inside diameter, as there is danger of the area facing the tuyeres "bunging up" so as to eventually stop its melting.

A permanent center tuyere, as illustrated on page 195, is not a convenient or practical device for cupolas under 50 inches diameter. To best meet the demands of small cupolas between 36 and 50 inches now in use, the author has been unable so far to design any device that would not necessitate being dropped with the bottom at every "heat," and the plan shown in Fig. 37, page 191, is one requiring the least labor to make blast connection, etc., that the author has conceived of for adoption with present cupolas. A plan that would greatly increase the practicability of using a permanent tuyere in small cupolas, between 36 inches and 50 inches inside diameter, is that of making them about 10 inches larger in diameter at their bottom than they would be, say, about six inches above the outside tuyeres. This taper at the bottom would, of course, enlarge the cupola so as to require more fuel for the bed than if the cupola were straight throughout its length, and thus, in some cases, partly annul the benefits to be derived from the "center-blast." While referring to the construction of new cupolas for special adaptation to "center-blast," it will be well to state that it is best, instead of making the outside

tuyeres on the pocket design seen in Fig. 40, page 195, to make them of the continuous design, as by such a plan a more uniform distribution of the blast around the outer circle of the cupola can be obtained, and the life of a lining increased.

Where center tuyeres are dropped with the bottom, there should be one or two extra tuyeres in reserve to replace any badly fractured ones, and instead of daubing these up, when they are erected in a cupola, they should be previously prepared and dried in an oven. By adopting such a plan, a chance is afforded of having a solid, permanent lining and filling up any cracks firmly with soft clay, after which the whole surface could be "blacked" over to still farther protect the new lining until it is hardened and glazed from the effects of its first heat in the cupola.

The thickness of clay to be used when first daubing or lining a tuyere should be put on the body of the center tuyere so as to project about one inch beyond the rings, numbers 1, 2, 3, 4, 5 and 6, Fig. 40, or M, Fig. 39, pages 195, 193, and after each drying keep adding a little to the clay's thickness until there would be a body of about three inches on the outside of the tuyere to protect the main tuyere casing or casting, C, Fig. 37, as the case may be. Accidents have happened by reason of the clay on the center tuyere wearing to a thickness permitting the liquid metal to burn through the casting C and hence start the tuyere to leak. To guard against this, it is a good plan to have two standard gauges to occasionally caliper the diameter of the tuyeres at its bottom and top, which, if found to be less in size than the gauges called for, could be built up straight between the bottom and top to give the

necessary protection, by patching on clay over the burnt out surface of the tuyere's lining.

In using the permanent center tuyere, originated by the author, shown in Fig. 40, page 195, it can often have its green clay daubed on with the tuyere in position and then by building a little fire at the opening of the center pipe, supporting the tuyere, the same can be dried, where the space of two or three hours will admit of such a process. It may be said that the same plan of drying could be adopted for the drop tuyere above described. Upon first starting in to use "center-blast," the author thought he was going to have difficulty in obtaining a material for lining that would stand the heat. Experience has shown that his fears were groundless, and all that is necessary is to use a fair grade of common fire clay, mixed with sharp sand, and to make the whole of a consistency found good to daub large ladles, or cupolas. Where fair fire clay cannot be obtained, it may often work well to strengthen common clays with plumbago, or coke blacking wet with a solution of silicate of soda. A center tuyere prepared in the manner above described will, after the first "heat," present a hard, glazed body, which may resist the high fusing effects of the cupola's heat for three dozen heats or more, and foundrymen thus using center tuyeres will often be surprised at the small amount of clay necessary to repair the tuyere and cap to keep them in good order.

While the author recommends carrying the center tuyere openings up to a height that may, in some cases, be six inches above the level of the outside tuyeres, he would caution all in not going any higher than necessary, as every inch of rise above the level of the

outside tuyeres brings the covering cap up nearer to the level of the first charge of iron, or "melting point," which, if approached too closely, is liable to cause injury to the cap by reason of the stock's friction in working downward, wearing away or breaking off pieces of clay at the bottom edge of the cap, A, B, Fig. 38, page 193. A good plan which I have discovered to work well, when charging the bed with iron, is to keep this first charge in a ring, as it were, leaving an opening fully the diameter of the cap in the center of the charge to be filled with fuel or coke. This plan prevents the first charge of iron from working down to come in contact with the covering cap and gives a body of fuel which remains over it for quite a period, sufficient, at least, to be effective of good results throughout the whole heat in affording protection to the covering cap.

In order to have about as hot iron at the commencement of a heat as will be found at the latter end, where "center-blast" is used, it is well to rob the first charge of fuel to raise the height of the "bed." Where this is not done, the first melting will often be found duller than that obtained at the latter end of the heat. Another point well to be mentioned is that of reducing the escaping flame and sparks generally found at the closing of a heat, where outside tuyeres are used only. By regulating the volume of blast through the center and outside tuyeres the cupola man will soon find he is able to almost wholly retard the escape of sparks or flames at the closing of a heat, which is generally best achieved by permitting most of the blast to pass through the center tuyere. Again, if any sparks should emanate from the center tuyere, from any cause, they can generally be stopped by

making most of the blast to pass through the center tuyere for a short period, thus giving further evidence of the advantage to be gained by combining center and outside tuyeres, as herein advocated.

It is not to be taken for granted, because the author has called attention to the unexpected that might happen to disable "center-blast," that any need be alarmed at its not proving a success. Mishaps can occur to outside tuyeres, and, in fact, almost any workings in founding. All that the author has done in thus calling attention to the liability of accidents occurring, is what any practical founder would do in providing for the worst and guarding to insure the best, provisions which, as a general thing, cause all to go well.

Since the first publication of Chapter XVII., page 176, the author is led to believe that many have been trying "center-blast" to do its introduction more harm than good, mainly through lack of experience in broad founding, and not knowing what may work well in one case may not do so in another. The author feels that this Chapter will show in what ways "center-blast" can be used with success, and will prove of much value in establishing its use. The above instructions are the result of three to four years of the author's experience in experimenting to perfect "center-blast" to a point to make it practical for every-day use, and any can adopt it upon the lines herein described, with an assurance that if fair judgment is used in first trying to utilize "center-blast," success will be assured and the results finally obtained demonstrate "center-blast" to be the most scientific and economical method yet advanced for cupola practice.

CHAPTER XXV.

INTRODUCTION TO NATURAL AND SUCTION-DRAFT CUPOLAS.

There is no machinery founder or moulder of long experience who has not, to a greater or less degree, imbibed a feeling of dread that something may break down to stop the blast and cause trouble before an important " heat " is finished. The author, for one, knows that a " break-down " at blast time has often caused heavy losses in castings, etc., and that fear of the unexpected happening just at the worst moment has often caused him much worry and many times led him to study whether a cupola could not be successfully operated with natural draft. The natural-draft cupola has many qualities to commend its adoption for certain lines of work, one of which is in sections of the country where a foundry is placed out of the reach of quick repairs, or situated where it would be desirable to dispense with an engine, its boiler, etc., and then again, in localities where boiler fuel is exceptionally expensive. It is also desirable for a class of work which might call for slow but continuous melting, as, for example, in cases where a founder has but little floor room or would prefer to avoid carrying a large number of flasks, etc., in order to produce a large day's yield of castings.

It will be evident from the above that the author does not wish to convey the impression that a natural-draft cupola could equal a forced blast one of the same size in fast melting. Of course, the larger a natural-draft cupola the greater the quantity of iron it would melt per hour, so that in reality it is only a question of size in order to insure all the speed in melting desirable; and were it not for the question of economy in fuel, in using large cupolas to melt small bodies of iron, it is plain that we could economically adopt natural-draft cupolas to meet the requirements of any shop for speed in melting.

The great advantage which a natural or suction-draft cupola offers in some instances to founding has weighed upon the author to such an extent as to cause him to seriously consider the practicability of natural draft, and as a result of his research, study and experience, he offers the design shown in Figs. 45, 46, 47, 48 and 49, Chapter XXVII., page 221, which are for the free use of anyone.

CHAPTER XXVI.

ALLEN'S NATURAL-DRAFT CUPOLA.

In a paper on melting without blast, published in *The Foundry*, April, 1895, Mr. J. McCash says:

In the November issue of *The Foundry*, I find, on page 99, a very good, practical article by Thos. D. West on the subject of blast for cupolas. He expresses the desire to use a cupola so constructed as to work without blast fans, etc. In 1854, I was employed in Allen's foundry, Springbank, Glasgow, Scotland, working on hollowware. About two hundred yards distant were located what were known as the "upper shops," supplied with three cupolas for making heavy work.

These cupolas used a blast from a fan and were built after the style of those days before the drop bottom came into use. A hole large enough to permit a man to enter was cut in the front, and through this the cinders were also drawn out after the heat. It was stopped up when the cupola was being got ready to melt, by using iron bars and wedges. When the heat was over it was knocked in and the cinders raked out.

After it had cooled off, the cupola man entered through this hole and dressed up the inside. In the shop where I worked, known as the "lower shop," all the light work was done and it kept busy twenty-five or thirty moulders, all of whom worked piece work, on stove plate and hollow ware principally. This cupola or furnace (in Scotland they were all called furnaces, as the word cupola was not used) was used daily and was oblong in shape, being about four feet the long way across by three feet the narrow way. The tuyeres were flat wedge-shape and were all the way around except the necessary places to support the upper part of shell, the inside opening of tuyeres being about five inches, the height from tuyeres to top being about ten feet, or

about equal to the charging door of ordinary cupola. The top was covered with a revolving cover resting upon trunnions at the ends and lined with fire brick. The charges of pig iron and fuel were placed on the cover and dumped inside by turning the handle, when the cover was brought back to its original position. Underneath the cover was a large flue, similar to that used in a brass furnace, entering into a tall stack; its exact height I do not remember, but it had sufficient draft to produce hot metal for light work. This furnace had been a long time in use and was erected about the end of the thirties or the beginning of the forties, although they had been in use in England for a great number of years previously. This cupola is seen in Fig. 44.

It was said that the owner, Mr. Allen, had to pay a royalty for the privilege of erecting it.

I do not know what the result would be, but it seems to me that a well built furnace of that description ought to melt iron more economically than the present method.

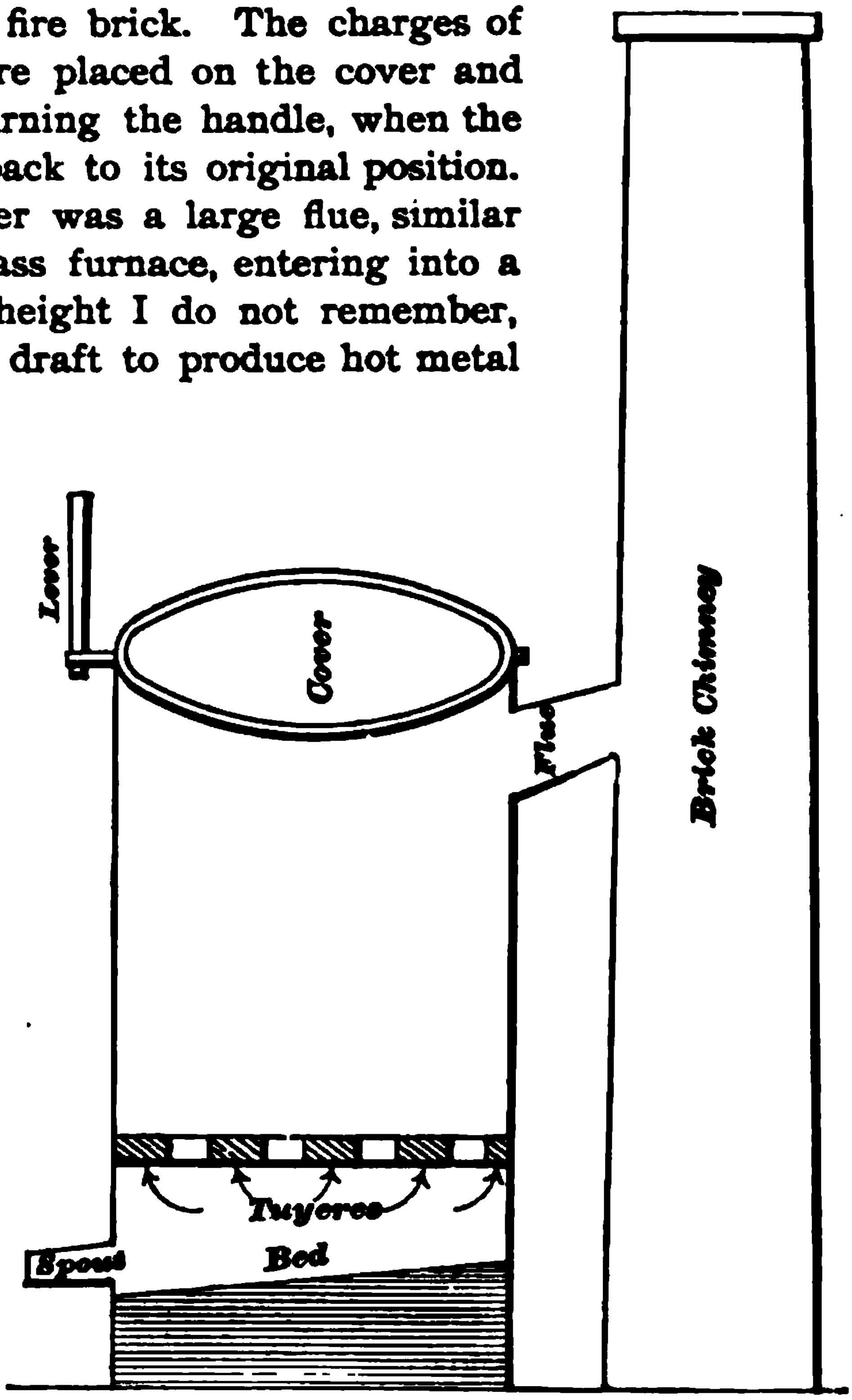


FIG. 44.—ALLEN'S NATURAL-DRAFT CUPOLA.

CHAPTER XXVII.

NATURAL AND SUCTION-DRAFT CUPOLAS.

This is a revised extract of a paper presented by the author to the Foundrymen's Association, Philadelphia, Pa., June 5, 1895. In a discussion on a paper treating of "The Herbertz Steam Jet Cupola," which was presented by Mr. J. B. Nau, before this same association, October 5, 1894, I called attention to the advantages of center tuyeres to aid natural-draft cupolas. The appearance in print of that paper, with its discussion, in the *Iron Age*, the *Iron Trade Review*, and *Foundry*, resulted in the last journal illustrating the workings of a natural-draft cupola which was used successfully in Allen's foundry, Springbank, Glasgow, Scotland, in 1854. See page 220.

The natural-draft cupola illustrated by Mr. McCash in *Foundry* probably presents the best success with which natural blast cupolas have met, and I largely attribute this to the fact of the Allen cupola being of an oblong shape, which admitted of air reaching the center body of its fuel much better than had it been of a round form. I am much indebted to a paper by M. A. Gouvy, Jr., on the different designs and principles in cupolas, which was translated from the French by W. F. Durfee, M. E., for the Franklin In-

stitute, and appeared in the Journal of the Institute in December, 1888, and January, 1889. This paper cites several instances of ill success with natural or suction-draft cupolas. In a study of the reason which can be assigned for their failure, I first found that every time a charge of stock was admitted to the cupola, a large area was opened which admitted such a volume of air at the top as to cause a decided check to the draft. All founders know that any temporary lull, no matter of how short duration, with force blast, checks the speed of melting and often results very seriously in causing "bung-ups," and shortening the length of a cupola's heat. The second bad point I found lay in there not being sufficient tuyere area and means for regulating the same according as the atmosphere influenced the draft, which is seldom found two days alike, no matter how high a chimney may be constructed. The third drawback I found was in not providing methods for the proper deliverance of slag, and prevent its rising to a level of the tuyeres, as it can easily do in a cupola as the length of a heat advances if not properly arranged for.

The writer has endeavored in the design here presented to overcome the evils above described and which to his mind have prevented the success of natural-draft or suction cupolas in the past. How far he may have succeeded will be best decided by a practical test and which could be most economically done by anyone having one or two high chimneys conveniently located, to which the draft for such a cupola as here shown could be connected. It is said that two chimneys of a medium height may often work better than one very high one. Fig. 49, page 229 (I have given all

the dimensions necessary for construction), shows a 40-inch cupola, mainly for the reason that this size is about midway between those in general use. To build smaller or larger cupolas than that shown, I would advise following the horizontal proportions and increasing or decreasing the vertical proportion (see page 230) by increasing or decreasing the height one-half of the measurement that the diameter proportions are increased or decreased. The total tuyere area for any size of a natural or suction draft cupola should range from 60 to 70 per cent. of the area of the cupola's largest inside diameter. The area of the continuous tuyere A is to be found by dividing the largest area of the cupola by two and the first row of tuyeres by nine, the uppermost row M by 20, and the center draft tuyere N N by dividing the largest area of the cupola by 35.

It is well to have the bottom or hearth portion of the cupola constructed wholly independent of the bosh and stock body, so that a perfectly continuous tuyere opening can be obtained, as seen at A. The upper and lower plates protecting the brick work at this tuyere are made of cast iron about one and one-half inches thick, the upper plate being best constructed of one continuous circle, whereas the lower plate could be in sections if so desired for convenience in being replaced should they crack or be burnt out in any way from outflowing metal. The upper plates are held in place to support the upper brick work by having a flange project upward on the outside and bolted to the shell as shown. To aid in supporting the brick work in the bosh and stack portion, angle iron, as seen at D, should be placed around the inner portion of the shell about

every two feet in height. The same columns used to support the bosh and stack portion of the cupola can, by having projecting flanges, as seen at E, Fig. 49, also carry the hearth portion, and this body can be raised or lowered so as to increase or diminish the

height of the continuous tuyere by means of "blocking" or jack screws placed between the flange E and the cupola's bottom plate as shown at F, by making the difference between the flange and bottom plate greater in distance than shown. "Blocking" is preferable to jack-screws, etc., as the latter, in many

foundries, can be made readily inoperative at such points by means of flying sparks of iron or dirt getting in between the threads of the screw or nut, or joints of levers.

To regulate the draft, a wrought iron gate belt about a half-inch thick is made to encircle the cupola as seen at H H, Fig. 49, and in the plan view, Fig. 45. To

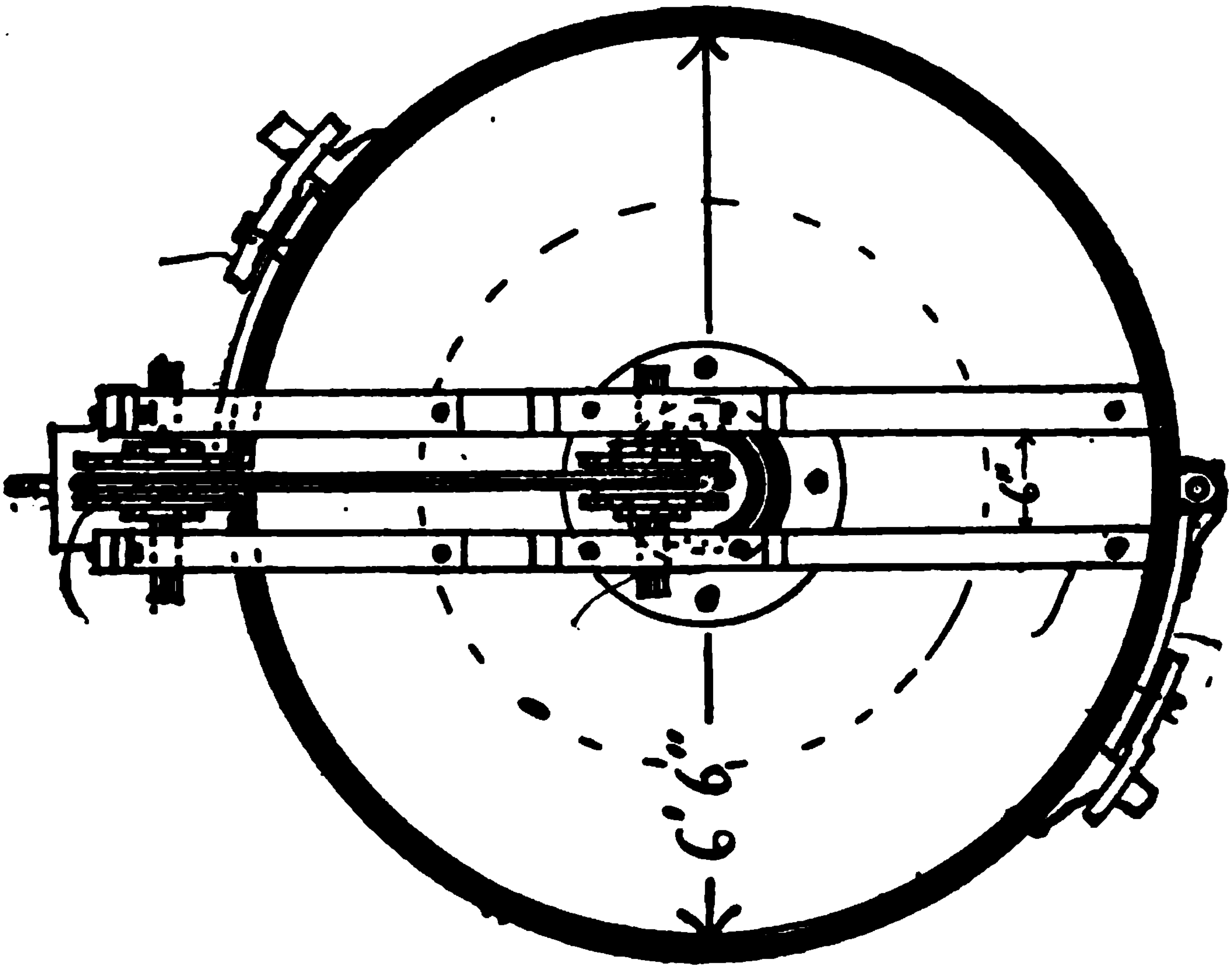


FIG. 46.—TOP PLAN OF CUPOLA.

raise or lower this belt, a weight G is used having two wire ropes I, passing over the pulleys J J, best seen in Fig. 45; the rope after passing over these pulleys, J J, is then carried down to come under pulleys or small sheaves seen at L in Fig. 49, passing from these to sheave wheels at right angles to L, secured opposite each other on the cupola's shell. At this point the

rope branches off in two directions on each side to connect with the gate belt at the points 1, 2, 3 and 4, seen in Fig. 45. Should it be desirable to secure this gate belt closely around the tuyere opening A, so as to shut off all possible admission of draft, this can be readily done by adjusting or tightening screws or clamps at the points A A, Fig. 45. To stop all draft passing through the center tuyere, a door is hung having the lug O, Fig. 49, for support at one side and a latch catch at the other. When these two openings are closed, in connection with stopping the breast with clay or sand and closing the chimney valve flue, we have a condition practically the same as that implied in the "banking of a furnace." To be able to thus bank a cupola, is a question worth raising. It is hard to predict how far this procedure may be utilized when the design of a cupola is such as to make it a success, as can be done by the design herein advanced. As an example of benefits to be derived from "banking" a cupola, I can remember when working for the Cleveland Rolling Mill Company as a journeyman molder, some years ago, it was a common occurrence for this shop to take off two "heats" a day without dropping bottom. I was often called out in the middle of the night, with a few helpers and cupola men, the latter to get their cupola ready, the former to assist me to mould up some broken casting or fix for the burning on of the neck of some broken roll, and generally cast it between the hours of five and seven in the morning. After the iron had been melted out of the cupola, the breast hole would be enlarged and the slag would be pulled out as it accumulated for about fifteen minutes, after which the breast would be closed

up with clay or sand and all tuyere holes, etc., made as air-tight as possible. Then, after a few shovelfuls of coke had been charged on to give a little fresh fuel to the bed, the charging door was closed and the cupola let stand in this condition until it was time to commence charging for the regular afternoon heat. Where a cupola is designed so as to be properly slagged and so as to prevent entirely any admission of air to the fuel by leakage through the tuyeres, shell

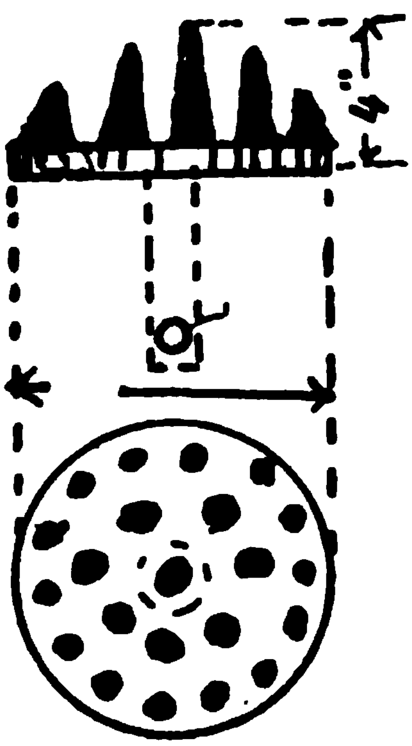


FIG. 47.

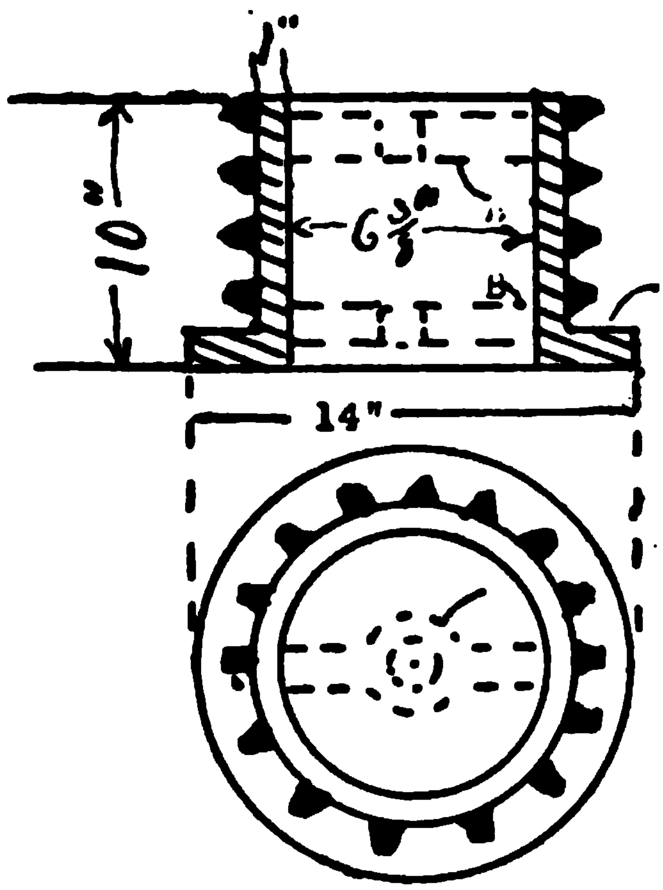


FIG. 48.

or otherwise, it is possible in shops that could use iron of a dullish nature at the first few hundred melted to run a cupola all week with light heats if iron is fairly clean without dropping bottom or pulling out all the "bed." Before leaving this subject of banking a cupola, I would call attention to the gate belt H in Fig. 49, being made with a taper recess at the outer edges as seen at R R. This admits of packing the

joints around the circumference of the gate belt and tuyere opening with clay to make the joint completely air-tight. For further information on "banking," see pages 127 and 132.

After the stock is charged around in the space at K as seen on the right at Fig. 49, the charging doors as at T are then closed as seen at X on the left, and then by pulling on the weight W, the conical cylinder Y (made conical to pull out of the stock easily) is raised and the stock slides down to fill the cupola.* According to the speed with which the closing cylinder Y is raised, so can the locating of stock be largely regulated as to its being chiefly charged to the outer or inner circle and thus afford facilities to arrange the fuel and iron at any desired portion of the cupola's area. This is a very essential point to insure uniformity in melting and lessening the chances of "bung-ups" and short-lived heats. Even where the charging arrangements as shown are not necessary for preventing an inrush of air at the top every time stock is delivered to the cupola, the point of insuring evenness and any desired distribution of stock in charging in itself recommends the adoption of such a charging device as here illustrated.

As arranged in Fig. 49, the charging cylinder cone Y can be raised two feet, and if this is not sufficient, the design may be modified to obtain any height desired. It will not be out of place to say that when it is necessary to charge massive pieces, this should be done after the bed or first layer of iron has been

* After the first publication of this Chapter, the author was made aware of a similar design charging hopper, to be seen in the *Iron Age*, June 18, 1891.

FIG. 49.—WEST'S NATURAL-DRAFT CUPOLA.

charged, so as to have the heavy pieces in the cupola lying in the last one or two charges near the top, and this should be done before the draft gates are opened to start the process of melting. It will be seen also that the principle involved in the charging arrangements will admit of raising the charging cylinder cone Y up out of the way to admit good light to the cupola, or the entrance of a man in making any repairs or lining a cupola, and also permit of the fullest freedom in passing down kindling to form the bed for first firing, or iron for the first charges in the cupola. The cone Y cannot drop into a cupola should the rope or chain used break. It would be well where long heats are run to have the cupola made two to three feet higher from the bottom plate to the charging ring than shown in Fig. 49. For height rules, see page 223.

This cupola thus designed can largely dispense with our present necessary evil of tapping out or stopping up, which is another new element that is an advance over our present practice. In long heats or where much slag is created it might be necessary to have a blow pipe or a jet of gas burn at the breast hole so as to prevent the slag chilling as it flowed out against the draft pressure with the iron. At the first meltings it might be found necessary in some foundries to bank the breast to a height near the top of the center draft tuyere opening so as to insure a body of metal quickly collecting in the revolving stand ladle seen at the spout of the cupola, Figs. 45 and 49. After a body of metal of about the height shown is collected in the stand ladle, the slag which may emanate from the cupola to float on top of the metal in the stand ladle or fine coke dust or blacking can be used to hold the

heat of the molten metal as to provide sufficient fluidity in the metal coming from the stand ladle to pour light work as well as heavy. For obtaining different degrees of fluidity as the iron comes from the cupola to the stand ladle we have recourse to the same methods which we use with force blast, which, with natural or suction draft, would simply mean regulation of fuel and the height of continuous tuyere or draft opening at A.

It will be noticed that I have planned a new form of stand ladle, one which can empty itself of iron on one side or slag on the other, without having to stop the outflowing stream of iron in its passage from the spout to the stand ladle. This stand ladle can be turned by hand or by means of spur or worm gearing. Should any desire to have such a cupola arranged so as to hold large bodies of iron before tapping, or to dispense with the stand ladle shown, they can readily do so by raising the height of the continuous outside tuyere and "center-blast" opening to whatever level desired, and then tap out as in regular practice.

It will be well at this point to discuss how natural or suction draft gives us promise of economy in all that pertains to melting. One advantage from natural-draft cupolas is that fuel is not necessary to raise steam to run fans or blowers. One shop may burn as much fuel to raise steam for a fan as is used in the cupola to melt iron. Another loss with the fan is in iron clogging around the tuyeres, due to the force of the blast. A natural draft moreover is less destructive to linings owing to the fact that we know a mild force blast is much less injurious to a lining than a strong forced blast. Again, the expense is saved of

keeping up repairs of belts, shafting, pulleys, fans, and all the appliances that are necessary to accompany a cupola using forced blast. There is a saving also in expenses often incurred by reason of bad castings and stoppage of work due to break-downs of appliances, in the form of fans, belts, pulleys, shafting, engines, etc., in a shop using forced blast.

While we must acknowledge that there are days when chimneys may have little or no draft, no matter how high they are, still this should not debar us from utilizing natural draft, as this objection could be often largely overcome by building a small fire in the bottom of a chimney through an opening provided for that purpose. Then, again, there are economical methods by which we could compel or obtain a suction draft on such occasions. We have not shown any chimney to accompany the cut of Fig. 49, page 229, but all are to understand that the flue XX seen on the right of the cut is extended for any length necessary to connect itself with one or more chimneys, the height of which will depend upon localities; and before any undertake the erection of chimneys, the author would advise all not thoroughly posted on questions pertaining to natural draft, to confer with some good mechanical engineer or ask for information on the subject through the agency of any good trade paper, and in doing so explain if the cupola is to be set in a valley or on a hill, etc.; also, what part of the world it is to be located in.

As regards the cost of the cupola shown, it should not exceed that of our present cupolas, when we consider the high stacks and blast pipes, etc., required; and as the chimney takes the place of the engines, etc., the

total expense should not be far from equal in both principles. When a founder endeavors to realize the striking contrast in practice between natural blast and forced blast, I think he will concede that the method advocated by this paper is one worthy of serious consideration, especially by those situated in mining countries or in localities where it is difficult to obtain repairs for break-downs, etc.

It is not a question whether iron will melt by natural draft, for this is demonstrated to be practical in the Allen cupola and is often done even in our present cupolas before the blast is put on, and to stop the iron from melting, tuyere openings are often closed to shut off natural draft. But the question is, can we melt fast enough by natural or suction draft? For some lines of work the author would say yes. One thing, however, is evident; if we cannot melt fast enough with natural draft, where quick melting is desired, we should often be able to do so with suction draft; and inasmuch as suction draft is not incompatible with the use of the cupola herein illustrated, with its several accompanying advantages and improvements, the design is commended as one means of escape from the rut in which our cupola practice has gone for so many years.

CHAPTER XXVIII.

CONTRACTED vs. ROUND CUPOLAS FOR LONG "HEATS."

Contracted or oblong cupolas "bung up" more readily than round cupolas, having as large an area at the tuyeres as above them. But to make the question clear in all its phases, it will be necessary to detail the action or process of "bunging up" as melting is continued in cupolas.

The action of a cold blast in entering a cupola chills the fuel adjoining the tuyeres. The metal dropping down on this chilled fuel solidifies and forms a body of combined shot-iron and coke, and in cupolas contracted at the tuyeres or built oblong, the process of chilling has a greater tendency to continue until the whole area facing the bottom tuyeres is bridged or chilled over, and in which case melting would cease, and the less height existing between the sand bed and the tuyeres, the sooner would this occur, especially so if the fuel and iron are of a nature to create much slag and the same was not well run off at the tap or slag hole.

A plain, round cupola, about the same diameter at the tuyeres as above or below them, would melt or run longer, all conditions being equal, than the oblong or contracted cupola of the same area. By "contracted" is

meant cupolas that are built so as to be considerably smaller at the tuyere than elsewhere, as shown in Fig. 51; as, for instance, we will take a cupola having a seven-foot shell, with tuyere two feet from the bottom plate. Some years ago cupolas were often lined after the plan seen in Fig. 51. Such a cupola would greatly obviate the " cold center," as far as getting the blast to the center was concerned, but its period for melting would be much shorter lived than with a cupola as seen in Fig. 50. These cupolas are supposed to be of about a seven-foot shell, and for such large size cupolas it is a good plan, instead of lining them strictly straight, to bring them in a little over the tuyeres, about as seen at B, for while this throws the blast a little better to the center, it at the same time greatly prevents the dropping melted iron from running into the tuyeres and the blast burning out the lining. Some advocate, when lining a cupola (also blast furnaces), to give it a shape the same as would be assumed after being in use for awhile, or for cupolas about as shown at K. There are some points in favor of such a plan, but in my practice I often have lined up large cupolas as outlined on the side at B; this insures the melting point existing longer ere repairs are required, and is a better plan than lining large

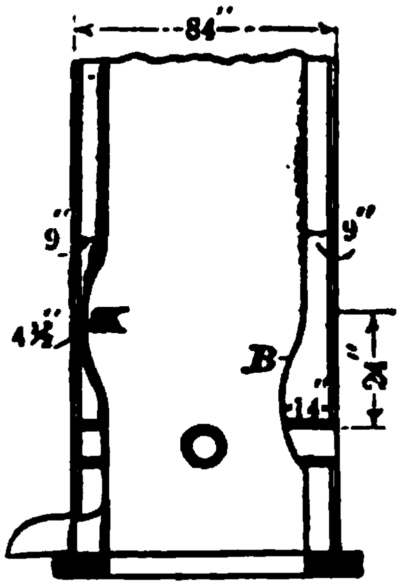


FIG. 50.—MODERN.

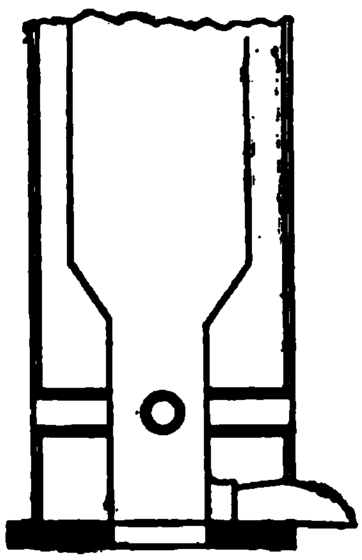


FIG. 51.—ANCIENT.

CONTRACTED VS. ROUND CUPOLAS.

cupolas as shown at K. The sketch, Fig. 50, shows the tuyere located in the lower part of the swell B. In most cases it would be best to have the swell B to start at the top of the tuyere instead of at the bottom, as here shown.

In melting large quantities of iron it is essential to have all the conditions possible to favor continued running without bunging up sufficient to bridge over or stop melting. We have but to look at the design or construction of cupolas used in Bessemer steel practice to get a pointer on this question. Here we find cupolas will run a whole week, night and day, without "dropping their bottoms," and, if some foundrymen run a cupola for ten hours, they would think miracles had been achieved, and so there would be in cupolas of some designs. The main secret of running steel work cupolas for a week at a stretch is in having high tuyeres and a good system of slagging out, combined with a straight lining or a partial following of the design shown at B, Fig. 50, and if such have upper tuyeres of one or more rows they often work much better where they only have one bottom row.

Some melters in running such cupolas do very little "poking at their tuyeres," and if their fronts should become clogged up they generally let them burn themselves out, as the refuse blocking up the front of tuyeres is chiefly only clean fuel caked together with chilled droppings of iron, their tuyeres being so high above the slag hole there is no chance for slag to reach up to them, which latter element is the greatest source for giving the melter trouble in foundry practice, on account of lower tuyeres. The author has tried the experiment of having more tuyeres than the size of

the cupola would call for, and having a damper arrangement so that the blast would be shut off, close up to the tuyere's entrance of blast to the fuel, from entering any of the tuyeres that might be showing a tendency to be bunged up, so as to prevent a fair admission of the blast. The action of thus closing the entrance of a "bunged-up" tuyere caused the blast from the open tuyeres to drive the heat toward the chilled or "bunged-up" collection of fuel and iron at the tuyere's opening, and eventually melt it down, so that when the damper is opened again the blast will be freely admitted to the cupola. For long "heats," especially in low tuyere cupolas, or those having little space between the tuyeres and slag hole, such a plan works well and often obviates the necessity of doing little, if any, poking at the tuyeres to keep them open in order to freely admit the blast. It will, of course, be evident, as intimated above, that such dampers must be arranged so as to be up close to the tuyere's entrance to the fuel, as, if too much void space is left, the effect of the heat is greatly diminished in its power to melt down the chilled droppings fronting the tuyeres. In order to open up bunged tuyeres, some have let a small flow of petroleum or coal oil run through a quarter-inch pipe to the bunged or chilled material, a plan said to work well in rapidly opening a "bunged" tuyere. When we say some steel works' cupola tuyeres are four feet above the bottom, the intelligent founder never having had an opportunity of seeing such work will be in position to comprehend why they are able to run so long without dropping bottom. Of course, most founders now understand the lower the tuyeres are in a cupola for foundry practice,

the greater the economy in fuel. It is for this reason that cupolas are made having low tuyeres, and in many foundries are essential to economy of fuel, but, nevertheless, many cupolas having low tuyeres would prove to give greater all-around economy, were their tuyeres placed higher. Science in melting points out that the height of tuyeres regulates the amount of fuel to be used for a "bed." No matter how high tuyeres are, we must fill up above them with fuel from 20 to 30 inches for coke, and 14 to 20 for coal, the difference in height being chiefly regulated by the weight of a heat and quality of the fuel and iron used. The larger the heat, the poorer the fuel, or heavier the iron, the higher should be the bed up to the above limit.

From a study of this, it will be apparent to all why oblong or contracted cupolas are not encouraged or used in concerns having large quantities of iron to melt at one heat, and will permit all to more fully conceive the purport in using the principles displayed in the bottom or side "center-blast" tuyeres illustrated by the author in these pages.

Mismanagement, or improper handling of material, is another reason why we find the plain, round cupola superior. With this class of a cupola there is much less likelihood of mismanagement, etc., causing losses and bad results, and it is this very fact that has led up to the popularity of the plain, round cupola. It is all very well for one to say that such and such should not be, but when we find we cannot always be on hand to prevent accidents or look after such matters, and the oblong cupola or those drawn excessively is a form most sensitive to the slightest error in mismanagement, we can but admit there are good grounds for

accepting the form of cupola which can be the least affected by mismanagement. I am not saying an oblong or radically drawn in cupola could not be used. It "bungs up" more readily and hence its use is not encouraged by firms having large quantities of iron to melt. A plain, round cupola, about the same diameter at the tuyeres as above or below them, would melt or run longer, the conditions being equal, than the oblong or contracted cupola. I admit, the oblong cupola is an excellent form to obviate the "cold center," but the objections above cited have relegated the oblong and contracted cupola largely to the rear. The "center-blast" attached to a round cupola insures the end sought by making a cupola oblong or contracted in a much more satisfactory manner, and is in keeping with blast furnace practice using protruding tuyeres (B, page 53), combined with forced blast to penetrate the center-stock to the more perfect combustion, uniformly, throughout the fuel. As high as 24 ounces pressure has been used in large cupolas, thinking thereby to force the air to the center to answer the ends of "center-blast." With cold blast, such only aggravates the tendency of "bunging," to diminish the length of time a cupola can run, and is destructive to fuel and linings. According to the area of a cupola, a certain volume of blast is required and the milder and more uniformly this can be admitted throughout a cupola, the better all-around economy is obtained. So far, no plan has been advanced to achieve this so well as "center-blast," combined with outside tuyeres, for cupolas over 50 inches in diameter.

PART III.

CHAPTER XXIX.

INTRODUCTION TO MIXING AND MELTING IRON.

A study of the following sixteen Chapters should enable founders to obtain mixtures for any general character of work desired, to determine how to do so with the greatest economy, and to exhibit the influence of one metalloid upon another. These elements are combined with a large number of other factors and are presented as necessary to be understood in mixing and melting for broad founding.

Chapter XXX. shows the effect of each metalloid in causing iron to be hard or soft, weak or strong, and treats of physical properties in iron, especially the abuse of silicon in causing weak, brittle castings, and the necessity for testing the strength of mixtures, as well as discussing elements on chilling iron.

Chapter XXXI. shows the metalloids that generally remain constant and those that are changeable or affected by the working of a furnace or cupola, in the making and remelting of iron. It also defines what metalloids should be adopted for a base in regulating mixtures or changing the "grade" of an iron.

Chapter XXXII. shows the impracticability of truly judging the character of iron by fracture and methods used in trying to determine the quality of iron by the

appearance of the top surface of pig metal. The Chapter also illustrates fractures of remelted iron in all the prominent specialties of founding, combined with an analysis of each of the respective mixtures.

Chapter XXXIII. shows how to order pig iron intelligently by analysis and how best to mix the same in readiness for charging.

Chapter XXXIV. illustrates how by a change in any of the metalloids, especially the sulphur, if silicon remains constant, a variation in the contraction can be greatly affected, and shows why, in referring to the quality of an iron, we should speak of it as "the grade."

Chapter XXXV. shows the necessity of reform at the hands of blast furnacemen, in respect to devising systems for insuring a thorough mixing of the different parts of a "cast," so that when a founder receives a "cast" or car of pig metal, one part will not be one per cent. higher in silicon than another; it also treats of the advantage of sandless pig castings.

Chapters XXXVI. and XXXVII. treat of Bessemer vs. foundry and charcoal iron and illustrate their special physical peculiarities, combined with a treatise on the differences of the chemical properties, showing what character of work each brand is best suited for, and in what manner such knowledge would promote the attainment of economy over present methods in making mixtures from such irons.

Chapter XXXVIII. should enable any one at all experienced in judging the grade of iron after it has once been remelted to utilize scrap iron with economy and assurance of its not diverting desired results in the various scrap mixtures used in founding.

Chapter XXXIX. defines what properties are in-

creased and decreased by reason of remelting iron, also treats of the humidity of the atmosphere.

Chapter XL. presents the strength of cast iron in all the specialties of founding and shows the chemical analysis of typical foundry mixtures.

Chapter XLI. gives a basis on which to formulate mixtures for chilled castings and treats of the different effects which heat and friction have on chilled iron and the qualities necessary for best resisting their wear.

Chapter XLII. illustrates how different degrees of hardness are obtained in chilled and "white iron;" tells how silicon can harden as well as soften iron, and discusses the fusing points of hard and soft grades of iron.

Chapter XLIII. presents proof of the affinity of iron for sulphur, also illustrates the effect which sulphur has in strengthening as well as in weakening iron.

Chapter XLIV. defines the chemical properties necessary to exist in electric or dynamo castings.

Chapter XLV. treats of the waste of iron by remelting, with a valuable discussion on the subject by several experienced founders.

Chapter XLVI. treats of the utility and composition of fluxes, showing the advancement necessary in this line in order to be in keeping with that made by chemistry in directing mixtures of iron.

Chapter XLVII. carries the reader back to the first days of experience with aluminum alloys, and shows their advance, and effects on cast iron.

CHAPTER XXX.

CHEMICAL AND PHYSICAL PROPERTIES OF CAST IRON.

Without chemistry we could not define elements causing physical effects or be able to scientifically and intelligently direct mixtures. The physical test tells us what is obtained. The chemical test tells us the metalloids we must use to effect results, and each property is essential to an attainment of the desired end. The first to be noted is carbon, as its influence in the form of graphite or combined carbon is the greatest in determining the character or "grade" of cast iron.

The amount of carbon which iron will absorb depends upon the working conditions of a furnace and the percentage of sulphur, silicon and manganese taken up by the iron. Much silicon reduces the power of iron to absorb carbon. The greater the percentage of manganese the more carbon can iron absorb, as is shown by "spiegel" iron, which contains carbon as high as six per cent. When iron is below .75 in manganese, about 3.50 of carbon is all it contains, although it may possess as much as 4.50 per cent. of carbon in rare cases. It is claimed that chromium, when substituted for manganese, will cause iron to absorb carbon as high as 12 per cent. The carbon in iron is ob-

tained from the fuel used in smelting. The more carbon iron contains, the greater influence silicon, etc., can have in affecting or changing the "grade" of iron. The carbon in gray iron is mostly in the form of graphite and the iron may contain as much as from three to four per cent. of it. Hard or "white iron" contains carbon in a different state from "gray iron." In "white iron" it is combined carbon, in which form it hardens the iron. The graphitic carbon in gray iron can have a large percentage made combined carbon, as in "white iron," by casting it on a chill or suddenly cooling it. By this action the carbon, which in melted iron is in the state of combination, does not have time to separate in the form of graphite.

Combined carbon is ascertained in true chemical exhibits of pig metal by the fracture being small grained, of a close, compact nature, and tending to a dark gray color in Nos. 2 and 3, and in the higher numbers to a lighter color. The higher its percentage in combined carbon, the greater the approach to white iron. The faster the iron cools and the more combined carbon it contains, the finer the crystals or grain. The lowest combined carbon is found in iron possessing from four to seven per cent. of silicon, and low in sulphur.

Graphitic carbon can be told in iron by the fracture being large grained and its crystals of a deep, brilliant color, from which flakes of graphite can often be extracted by hand or brushed out. A large percentage of graphite in iron will make it very soft, unless retarded by the presence of some hardening substance, such as sulphur. The more slowly a casting cools and the more graphite in the iron, the larger the grain.

For characteristic determinations of combined carbon in a fluid state, see Chapter L.

Total carbon is that composing the combined and graphitic carbon united. Where the total is known and only the combined is stated, the balance necessary to make the total would be the graphite, and the reverse, where the graphite is only known.

Woolwich's experiments have proved that variations in the percentage of combined carbon are more effective in changing the grade of an iron than equal variations in graphite carbon. A slight increase in graphite, with the combined carbon remaining constant, creates very little effect in the ratio of the two forms of carbon to each other, but if a like change should be made in the combined carbon having the graphite remain constant, the ratio would be greatly changed and the "grade" of the iron would be very much altered.

Silicon's chief office is to soften iron and aid the founder to regulate or cheapen his mixture. This was first suggested by Dr. Percy, some thirty-five years ago, but it awaited experiments in 1885 by Mr. Charles Wood, a founder of Middlesbrough, assisted by John C. Stead, the expert chemist, both of England, to first practically demonstrate the value and utility of silicon as a softener and its application to founding, a work which, it should be said, had its foundation laid in experiments conducted by Prof. Thomas Turner, at Mason College, Birmingham, Eng., the same being presented a few months later at the Glasgow meeting of the Iron and Steel Institute. The extensive publication of this paper is really responsible for the universal adoption of silicon as a softener and element in mixtures of iron. The next to take up

this work was M. Fred Gautier, of Paris, who, at the next spring meeting of the above association, presented a paper on silicon in foundry iron. These two papers started many others experimenting, among the most prominent being Mr. W. J. Keep, of Detroit, Mich., and the author.

Not only is silicon a softener of iron and a great element in cheapening the mixture by permitting a large percentage of scrap or cheap iron being mixed with high-silicon iron, but it is also an element of value in increasing the fluidity of metal. Silicon possesses a property which, in a degree, reduces the percentage of total carbon which iron may take up, and which also can exceed in its percentage any other element in iron. It has found such a favor in the estimation of some as to make them unregardful of any other element in iron, a practice which is decidedly wrong, from the fact that one part of sulphur can often neutralize the effect of ten to fifteen parts of silicon, and hence for this reason it is as essential that the founder should be as watchful of sulphur as silicon, and the same may be said of the other metalloids—phosphorus and manganese, as all should be considered in making mixtures; but the silicon and sulphur should be considered the bases for changing the grade or character of iron, as seen by Chapter XXXI.

The author's experience and study of silicon in its effect upon mixtures lead him to affirm that while it can achieve much good, it can also do great injury. It is an element which should only be used with a knowledge of the effect any percentage can produce, just as a physician can administer a poisonous drug to obtain beneficial results. Silicon is a very good thing, so is

good whiskey, but either, if not carefully used, can cause more evil than good. For this reason, guesswork in judging the amount of silicon an iron contains is not to be commended. Only by a knowledge of its chemical analysis can constant, uniform or desired results in applying silicon to mixtures be best maintained. I have found that silicon had a softening effect up to a percentage where it was possible to have castings jolted in safety over a pavement or rail track in transit for delivery.

This is as far as the founder ought to go in using such "poison" to strength. After the carbon has become graphitic all it will, any further addition of silicon only closes the grain and makes the casting "soft rotten," or brittle. If, by still further addition we would exceed four per cent. of silicon—which is a percentage no ordinary iron mixtures or casting requiring any strength at all should contain—we may then harden the iron to a slight degree. A mixture having four per cent. of silicon is as high in that element as it is practical to use, if we expect general castings to hold together, unless the sulphur or manganese is very high to harden the iron. It is not desirable to have ferro-silicon iron in castings. Very few mixtures or castings, excepting those for electrical purposes, require over three per cent. of silicon in their composition, if the sulphur or manganese is right, and the lower this constituent can practically be kept in most castings the better the results to be expected from its use.

In Russia, they have made light castings, as was shown in the exhibit at the World's Fair, 1893, with the silicon as low as .55, a little over one-half of one per cent., but in order to achieve this, we find the

sulphur did not exceed .022. This is a good example in illustration of the effect of sulphur in hardening iron, for had the sulphur been .06, as is generally the case as an average for light castings in America, with the silicon only .55, such castings would be so hard or "white," that they would never hold together long enough for one to handle them. The low sulphur in the Russian castings would lead us to say that they were made from cold blast charcoal iron.*

Silicon can be absorbed by iron to as high as 20 per cent., and from 3 to 5 per cent. of silicon in mixture will generally change all the carbon found in ordinary irons to graphite that is possible to be changed. The percentage it will require to do this is dependent upon the percentage of the other constituents present in the mixture. Silicon ranges from 1 to 5 per cent. in foundry iron, in standard Bessemer iron from 1 to 2½ per cent., and in ferro-silicon pig iron from 5 to 14 per cent. In making mixtures of iron with pig containing 4 to 6 per cent. of silicon there is far less risk of over-dosing a mixture than with pig containing from 8 to 14 per cent. of silicon, for although we may figure out to a nicety just the percentage pig may contain and direct how many pounds should be charged, it cannot but be seen that with the higher percentage of silicon pig the least error in weighing it, etc., could be very disastrous in results. In cases where a founder has a cheap class of work and desires to use all the scrap, burnt or hard iron possible, he may often use

* The Russian analysis was obtained by Mr. H. L. Hollis, of Chicago, and presented in a table with other analyses of American castings in a paper read before the Western Foundrymen's Association, May, 1894.

ferro-silicon pig very economically, or where a founder is running on a specialty of any kind that does not require different mixtures out of the same heat, with good judgment and care, ferro-silicon may often be well and profitably applied in mixture. Four per cent. of silicon pig can often carry 80 per cent. of ordinary scrap to make soft, machinable castings in work not under one inch in thickness.

Silicon in the pig has a silver cast, and, with some grades, a flaky, frost-on-the-window look. It has practically no grain and when broken has a fracture somewhat like glass. For its appearance in a liquid state, see Chapter L.

Sulphur in iron is mainly derived from the fuel used to smelt it in the blast furnace and in remelting it in a cupola. It is the most uncontrollable, injurious element the furnaceman or founder has to contend with. There are, however, three qualities sometimes commendable in it: one is its influence in increasing the fusibility of iron, and another its strength, as shown in Chapter XLIII., and the third its tendency to harden or chill iron by reason of its promoting combined carbon, which is often better obtained with low silicon or high manganese, since with these we have less injury from unyielding contraction strains. With the exception of the three qualities mentioned above, the effects of sulphur are greatly for evil, making light castings hard and molten iron sluggish, and giving rise to "blow holes" in iron solidifying rapidly. It is for these various reasons that charcoal iron, on account of its being low in sulphur, has been found superior to coke or anthracite iron for many kinds of castings.

With charcoal iron castings we can have low silicon without much sulphur, whereas with coke and anthracite iron castings, if we have low silicon, we may generally expect high sulphur. Charcoal pig metal being the most free from sulphur and impurities, the softest strong castings are obtained from it, especially when melted in an air furnace. Sulphur is very deceptive in pig metal. It can lurk in hiding so as to be present to a much greater degree than the eye of an expert can suspect. For this reason chemical analysis is very essential in order to ferret it out. Sulphur can cause iron to be red short, as well as cold short.

Two parts of sulphur are more effective in changing the character of iron from five to twenty parts than any other constituent which iron possesses. Its influence in so greatly changing the character of iron is due to its ability to radically increase the percentage of combined carbon in iron. The alteration that a few points in sulphur can effect in the "grade" of iron is often surprising, and for this reason founders should be most watchful of sulphur. The amount of sulphur in pig metal generally ranges from .01 for No. 1 iron up to .05 for "white iron." For No. 1 pig metal it rarely exceeds 0.03; Nos. 3 to 4, 0.05, and for white pig iron 0.08. Sulphur in iron can cause excessive shrinkage as well as contraction, the former often being the cause for shrink holes and the latter for cracks in castings.*

Manganese, when increasing the combined carbon, will deepen the chill and cause greater shrinkage and contraction, and to a limit greatly strengthens iron.

*For an article on the effects of sulphur in strengthening iron, see Chapter XLIII.

Manganese is readily absorbed by slag and can be carried off as oxide of manganese during a heat, and in cupola work will greatly assist in carrying off sulphur by means of "slagging out." Manganese ranges from a trace up to 3 per cent. in pig iron. The general run of good grey pig iron averages about .50. Over this proportion it would, in light work, unless proportionately higher than 2.50 in silicon, be injurious in causing castings to harden, and it is seldom in massive work requiring strength that it would be beneficial for manganese to exceed 1½ per cent. Manganese can counteract the red shortness caused by sulphur and greatly neutralize the effect of silicon pig to soften iron mixtures. It can be used as a physic to purify liquid iron. If the iron is high in sulphur it will be beneficial in expelling it and thereby lessen the chances of "blow holes" by reason of softening the iron.

A very peculiar property that has been noticed in pig iron containing 2 to 3 per cent. of manganese is that while it will look open-grained, like a good No. 1 soft iron, it has been found so hard that it could only with difficulty be drilled. Manganese gives fluidity and life to molten metal, causing it to occupy greater time in solidifying. In pig metal, also castings, it can cause the crystals to be large grain, though the iron can be hard, as above stated.

Manganese is often found to range as high as 2.00 in foundry pig metal and still make good machinable castings. This quality is attributable to the great activity which manganese has for expelling sulphur in remelting iron. Sulphur is the element of greatest power in causing hardness in castings; but, on the other hand, sulphur can be largely eliminated by man-

ganese; hence the reason why manganese can often be high and still soft castings be obtained. The better a cupola is fluxed and the higher its temperature, the more the manganese will be decreased. In making or remelting iron, manganese is affected in a manner somewhat similar to silicon. A hot working furnace will send the manganese into the pig, where a cold working furnace will send it into the slag, as it requires high heat to make manganese combine with the iron, when making it.

A phenomenon peculiar to manganese is to be cited in the opposite results which manganese exerts when in the pig, in process of being melted, and when it is added as ferro-manganese to soften hard grades of molten metal, as is practiced by some founders. The author cannot explain the phenomenon better than by here inserting comments by Mr. Alexander E. Outerbridge, Jr., in a paper presented by him before the Franklin Institute, February 2, 1888:

A remarkable effect is produced upon the character of hard iron by adding to the molten metal, a moment before pouring it into a mould, a very small quantity of powdered ferro-manganese, say one pound of ferro-manganese in 600 pounds of iron, and thoroughly diffusing it through the mass by stirring with an iron rod. The result of several hundred carefully conducted experiments which I have made enables me to say that the traverse strength of the metal is increased from thirty to forty per cent., the shrinkage is decreased from twenty to thirty per cent., and the depth of the chill is decreased about twenty-five per cent., while nearly one-half of the combined carbon is changed into free carbon; the percentage of manganese in the iron is not sensibly increased by this dose, the small proportion of manganese which was added being found in the form of oxide in the scoria. The philosophical explanation of this extraordinary effect is, in my opinion, to be found in the fact that the ferro-manganese acts

simply as a de-oxidizing agent, the manganese seizing any oxygen which has combined with the iron, forming manganic oxide, which, being lighter than the molten metal, rises to the surface and floats off with the scoria. When a casting which has been artificially softened by this novel treatment is remelted, the effects of the ferro-manganese disappear and hard iron results as a consequence.

The value and importance of manganese in giving characteristic qualities to iron are not to be underrated, and it is always to be remembered that it has its field for effecting desirable results in certain special lines of casting, as outlined in this work.

Phosphorus is the element which differentiates "Bessemer" from "Foundry" iron, and generally ranges from a trace to 1½ per cent. in ordinary pig metal. In foundry iron it generally varies from .25 to 1.00, and it can be found in iron as high as 7 per cent. If iron exceeds .10 in phosphorus, it is no longer regular Bessemer, and may be often classed as foundry. To make this distinction between Bessemer and foundry iron clear, Table 20 is presented:

TABLE 20.—CHEMICAL ANALYSES OF FOUNDRY AND BESSEMER IRONS.

	No. 1 Foundry.	No. 2 Foundry.	No. 1 Bessemer.	No. 2 Bessemer.
Phosphorus	.60	.50	.09	.09
Graphitic Carbon	3.50	3.00	3.50	3.00
Combined Carbon	.15	.30	.35	.65
Silicon	3.00	2.25	2.00	1.25
Sulphur	.01	.02	.025	.050
Manganese	.30	.40	.50	.45

As can be seen by the above Table, excepting phosphorus, the four analyses could pass as foundry iron. Further comments on foundry versus Bessemer will be found in Chapter XXXVI.

Over seven-tenths of one per cent. of phosphorus

can cause iron to be "cold short," which means brittle when cold, and it can harden iron where sulphur is low, if used in excess of from 1.50 to 2.00.

By keeping phosphorus down to between 0.40 and 0.60, with silicon from 1.70 to 2.00 in foundry iron, thin castings can often be made so as to bend or twist to a surprising extent and also admit of cast iron being readily punched with holes similarly in some degree as would wrought iron be affected by like treatment. It has been contended that phosphorus is in no wise beneficial to the strength of an iron, but Woolwich's experiments have proved that phosphorus running from about 0.20 to 0.70 is beneficial in improving the desirable qualities in physical tests for cast iron work. Phosphorus is chiefly obtained from the ore and flux. It retards the saturation of iron for carbon and adds fluidity and life to metal. It is the most weakening element iron can possess when used in excess, and is often objectionable when it exceeds 1.00 per cent. in foundry iron, in which it is best kept down to not exceed .80. Necessity for extra fluidity, or life, to the liquid metal is the only occasion where phosphorus to exceed .80 in foundry iron should be permitted.

Phosphorus is an element very essential to the success of founding. In many instances it needs to be guarded as closely as sulphur or silicon, and an intelligent use of it will prove that it can forcibly influence mixtures and the life and wear of castings. As far as the author can learn, Mr. James A. Beckett, of Hoosick Falls, N. Y., has excelled all others, including the author, in experimenting in a practical way with phosphorus as an agent to regulate actual mixtures

used in a foundry. He writes the author that he has found it to greatly counteract the tendency of sulphur to increase combined carbon and that he has, upon several occasions where high sulphur was giving trouble in making castings hard, by increasing the phosphorus from 0.50 to 0.75 made castings soft, that could not be otherwise machined. Of course, he could have attained the same end by increasing the silicon or reducing the sulphur, but conditions permitted Mr. Beckett to experiment with phosphorus in order to obtain knowledge as to its exact influence when the other metalloids were remaining fairly constant. His experience in this line is of much value, and it gives the author pleasure to record them here, as Mr. Beckett is known to be a practical founder. Mr. Beckett's experience in regulating mixtures by phosphorus also confirms the fact that each tenth of one per cent. increase of phosphorus will give about the same results, physically, that an increase of one-quarter of one per cent. silicon will give, if the phosphorus is unchanged, until the total quantity of phosphorus reaches the limit of safety, viz., 1.00 per cent., and that mixtures in which the fluidity is increased in this way within such limits will be found to produce castings freer from blow-holes and shrink spots than if silicon were entirely depended upon for giving fluidity.

Chromium, as shown by Thomas Turner,* is not uncommonly present in small quantities in ordinary iron ores. It has been found as high as .12 in samples of pig iron, by J. E. Stead.† It greatly increased the power of iron to absorb carbon up to 12 per cent.

*Metallurgy of Iron, page 205.

†Iron and Steel Institute Journal, 1893, Vol. 1, p. 168.

Especial alloys of iron and chromium, called ferro-chromes, containing as high as 84 per cent. of chromium, are shown by Turner to have been attained. He also says that though ferro-chrome is more refractory than ordinary cast iron, and is very fluid, it runs "dead" and solidifies rapidly, and that it renders iron hard, white and brittle, behaving in an exactly opposite manner from silicon or aluminum. Much more might be said of this constituent, but as it has been found up to the present time of little value to founding, space is reserved for more important elements.

The constituents of iron, carbon, silicon, sulphur, manganese and phosphorus, above described, are recognized as the chief elements in controlling the character of iron. Aluminum, magnesium, sodium, potassium and calcium, also titanium, copper and arsenic, are properties found in iron. But of late years little note is taken of them by chemists, and they are now regarded as having practically little, if any, weight in affecting mixtures or the character of commercial iron, and hence we have omitted to discuss their characteristic qualities to any length in this work. We might state that titanium was at one time used to some extent in obtaining strong iron, but owing to it being very refractory in its ores, causing great trouble in smelting, it is now little, if any, used.

Pure iron is a quality often referred to in metallurgical works, and was held at one time as the ideal to be attained. Pure iron is a metal combined with at least two per cent. of carbon and almost wholly devoid of the elements sulphur, silicon, phosphorus, etc., mentioned above as existing in commercial cast iron. In appearance, pure iron resembles a high grade

of "white iron," and in a fluid condition is of a thick, sluggish nature "hard to run" and gives a casting full of "blow-holes." By mixing silicon with "pure iron" it can be made to run and give a sound casting, but by such a mixture it could not then be called "pure iron," which in itself possesses little strength, having no commercial value.

The physical properties of cast iron may be said to consist of density, tenacity, elasticity, strength, toughness, brittleness and chill. These may all differ in having characteristic qualities in different brands or classes of iron. The first of these elements is to be attributed to what is called the "grain," and the degree of density is the basis of grading our iron from No. 1 (our most open, large-grained iron) up through Nos. 2, 3, 4, 5, 6 and 7; the latter two being almost as close grained as a piece of glass, and generally called "white iron." A cubic foot of white iron weighs about 60 lbs. more than a cubic foot of No. 1 iron. "White iron" will sink in a ladle of liquid No. 1 iron, whereas a piece of No. 1 would float on its surface.

Tenacity of cast iron is that element which resists a pulling apart of its body or a separation of its molecules, as by a tensile strength test.

Elasticity is that quality which permits cast iron to stretch or bend and then return to its original position or shape when the load is removed. Should the load be so great that the iron will not return to its original shape, it partakes of what is called a permanent set, or has reached its limit of elasticity, a point which, when attained in cast iron, is very close to the breaking load.

Average cast iron, when sound, "stretches about .00018, or one part in 5,555 of its length; or ⅛ inch in 57.9 feet for every ton of tensile strength per square inch up to its elastic limit, which is at about one-half its break strength. The extent of stretching, however, varies much with the quality of the iron, as in wrought iron."* For further information on the stretching qualities of cast iron, see Chapter LV., page 419.

Toughness may be defined as strength, but applies more properly to that quality permitting cast iron to bend before it breaks, and in transverse testing, such is called "deflection" and again resilience.

Strength of cast iron is its ability to resist transverse, tensile crushing, and impact blows or strains, and, in a sense, includes tenacity, elasticity and toughness. It is very rare that castings are designed to resist other than transverse or crushing loads. For this reason transverse tests are the forms of testing mainly used to obtain knowledge of the strength of cast iron, as in securing the transverse strength of test bars, we can also note the "deflection," a quality which tells us of the ductility and toughness of iron better than any other present method can. Deflection also to a great degree informs us of the softness of iron.

Brittleness is that quality adverse to strength and is greatest in "white" or "chilled" grades of cast iron, also high-silicon mixtures.

Chill is that quality producing a "white" or crystalline body in iron. It can be produced by rapid cooling or by having high sulphur or low silicon, which produce, in the carbon, a state opposite that of graph-

* Trautwine.

ite. It is a physical element desirable to exist in order to best resist friction surface wear, and is chiefly employed in such castings as rolls, car wheels and crushers. A special article on the "chill" will be found in Chapter LVI.

We might say there is chiefly but one carbon in iron, and whether it is combined so as to create a "chill," or graphitic to make soft or open-grained iron, largely depends upon the time taken for the metal to cool down to solidification, or atmospheric temperature. We can take our softest irons, highest in graphitic carbon, and by pouring when liquid into water cause their carbon to be largely combined in the iron; and then, again, we can take our hardest or "white" irons, that are not high in manganese or chromium (qualities seldom to be found in general castings), and by pouring them into massive castings, like heavy anvil blocks, cause their carbon to appear largely of graphite, thus proving that it is chiefly a mechanical or physical condition, and not chemical, that ofttimes can cause iron to be soft or hard, or present peculiarities in its physical qualities.

The above illustration of pouring liquid iron into water and cooling off massive blocks or castings presents the radical extremes of any physical effects. In the rational, common practice of founding, conditions admit of the chemical properties having a control which compels us to recognize them as the chief factor in diminishing or increasing the combined carbon or the hardening qualities of an iron. Nevertheless, a study of what physical effects can produce will prove to many how two castings can often be poured from the same ladle of iron so as to have the same percentages of sili-

con, sulphur, phosphorus and manganese exist in the two castings, and still have the combined carbon much higher in one than in the other.

Concerning the principles pertaining to the strength of cast iron, we find the most lamentable ignorance exists. Some understand that there is such a thing as soft and strong grades of iron, but when you have the latter practice ignored and the first exacted until the product approaches lead, it is time to stop and see whither we are drifting. The machine builder, ignoring strength but finding his castings growing softer, has encouraged the foundryman in giving such soft castings, until to-day many of our machines might as well almost be made of so much glass. Such practice injures the reputation of cast iron and encourages its replacing by steel, etc. It is not to disparage the founder that the author writes of this subject, but if possible to awaken thought and action toward a movement by the builders of machinery for the exercise of some reason and the attainment of knowledge as to where to draw the line at wanting softness at the sacrifice of strength. Before the founder knew so much about silicon, and had good luck in mixtures, his castings would generally show a rich, dark, open fracture, making a strong, soft casting, instead of being found, as to-day with many, in a close, silvery-grained grade, making a soft, rotten, leaden casting.

In using silvery or silicon pig to any extent in mixture there is a very fine line to be drawn in the use of just enough to attain the happy medium approaching strength and softness. Some would rather take their chances of being over the line than under it, and many, if they would only confess, have gone over the line so

far that in the morning after a "cast" they have often found some of their castings lying around the "floors" in sections that had not been so designed by the draftsman. Further information upon the physical qualities of iron will be found in the various Chapters comprising Parts III. and IV. of this work.

CHAPTER XXXI.

CONSTANT AND CHANGEABLE METALLOIDS AND REGULATIONS OF MIXTURES IN IRON.

It is to heavy founding that we must chiefly look for the best opportunities for obtaining knowledge of the manner in which the various metalloids affect the carbon in giving characteristic qualities and in changing the grade of iron. This arises from the simple fact that in heavy founding, castings of all grades are demanded. Then again, in order to obtain accurate information we must deal with actual practice, for physical conditions in founding can often affect the character of iron or the condition of its carbon as much as changes in its chemical composition. Tests of iron from a crucible, etc., are of little value in advancing practical knowledge and have only created confusion of methods and ideas on the effects of metalloids. This has gone to such an extent that the majority of seekers after information upòn the metallurgy of iron are more confounded than enlightened on many points.

Some advise regulating the mixture or changing the "grade" of the iron by means of alterations in the percentage of silicon; others by changes in manganese, and again others, by changes in phosphorus. To illustrate the effects of each element and as a demonstration

of what I consider the best base for regulating mixtures, I would carry all back to the making of iron. I would consider what are the constant and what the changeable metalloids, in order to discover what elements are really responsible for changes in the character of pig iron, as it comes in "brands" to the foundry yard. If, in making iron, all the metalloids remained fairly constant, not varying in their percentages, one "cast" after another, we could obtain a uniform product and have no such thing as grades of iron from like mixtures of ore, fuel and limestone. But this is not what exists. Instead of uniformity we find that a furnace cannot at the present stage of furnace advancement make two "casts" alike, and hence we find that any furnace will, from the same mixture of ore, fuel and limestone, give a wholly different "grade" or analysis of iron at almost every "cast." Now, the question simply narrows itself down to this: Are there metalloids that cannot be controlled? Are there those whose erratic action causes a diversity in results? Experience answers, "Yes," and analyses prove that silicon and sulphur are the metalloids wholly responsible for creating the difference in grades of iron, coming from similar mixtures of ore, fuel and limestone in smelting, from the fact that the total carbon, manganese and phosphorus generally remain practically the same, one "cast" after another.

When the same stock is used in making the iron, silicon and sulphur jump around in such a lawless manner that the most radical difference may be expected in "grades" in the various "casts." A furnaceman can be most particular and have all conditions alike, so far as is in his power, yet for all this no two

"casts" will be alike in silicon and sulphur contents. Now if it were in the power of the furnaceman to maintain the same uniformity in the silicon and sulphur that he generally secures in the case of total carbon, manganese and phosphorus, there would be no difference in the grades of iron, and all would be practically the same in physical qualities. In all that I have written on this subject, I have made silicon and sulphur the basis of calculation and have contended that as much importance should be attached to knowing the percentage of the one as of the other. I still maintain that this position is correct and that this is the right practice to follow. In making iron, the furnaceman can control the percentage of manganese or phosphorus in his iron by his mixtures of ores, fuel and limestone to obtain practically any specialties he may want, whether of high, medium or low manganese or phosphorus iron. What little variations may occur in the percentages of these two metalloids in irons will have no practical effect on the carbon to change the "grade" or the character of the iron coming from one mixture of ores, fluxes and fuel.

It is to be remembered that I do not claim that manganese and phosphorus cannot affect the carbon or the character of iron. Either of these can change the physical qualities just as variations in the percentages of silicon or sulphur change them; but we must look to the furnaceman to do this in preparing his mixtures of ores, lime and fuels in making the iron. If any one desires an iron high, medium or low in manganese or phosphorus, he can generally get it so even in its percentages as not to affect, in a practical way, the "grade" or physical qualities of the iron which he de-

sires to obtain, and this can generally be achieved, day in and day out, at every "cast," as long as the furnace continues to use the same ores, fuel and flux. On the other hand, silicon and sulphur will vary at every "cast," in spite of all the present furnaceman's calculations, and it is the changes in these two metalloids that we should consider as affecting the "grade" of iron, or in causing it to vary in its percentages of graphite or combined carbon. This makes evident what are the metalloids that the founder should recognize as bases for changing the "grade" of his mixtures or physical qualities obtained in the castings produced.

Although furnaces are unable to control the silicon and sulphur in always being uniform at the present day, the author has faith that future advancement of practice in attaining more uniform temperatures steadily in a furnace will bring about a great improvement in this line; nevertheless, silicon and sulphur will always be the metalloids subject to change the "grade" of iron where the same ores, fuel and fluxes are used and be the elements to which the founder should look for making variations in the "grade" of a furnace product, working on one brand of iron, or in making or altering mixtures for the founder in remelting iron.

It is intimated above that the total carbon is not perceptibly altered where the same fuel, ore and limestone are used when making iron. This is to be understood as referring to iron being made under normal conditions which insures a furnace running without having any "slips" or factors to cause an excessive cold or hot working furnace. The opinion of a few furnacemen with whom I have discussed this point is to the effect that the higher the temperature and the more

slowly the ore passes down to the hearth as iron in a fluid state, the greater total carbon will be found in the iron. This is to be taken only as an opinion, based on good reasoning, as I have failed to find any furnace-men that have followed these relations by exacting analyses to know positively what radical changes in the temperature of a furnace or the speed of reduction would make in the total carbon, where the same ores, fluxes and fuel are used. However, what slight changes may be made in the total carbon by normal working of a furnace can have little effect in changing the "grade" of an iron; and this leaves us to recognize the silicon and sulphur, as stated above, to be the metalloids chiefly responsible for giving us "grades" in iron from similar mixtures of ore, fluxes and fuel, and also that to effect changes in "grades" of remelted iron comprising one class or brand of metal. For information regarding the effects of the other metalloids, manganese, phosphorus and total carbon in changing the grade of iron by the use of different percentages of these constituents in varying "brands" of iron, see Chapters XXX., XLI., XLIII. and LXX.

CHAPTER XXXII.

JUDGING CAST IRON BY FRACTURE AND FACE OF PIG IRON.

Before the advent of chemistry in founding, foundrymen had to be "hauled over the coals" almost daily about some casting being too hard or not of the quality desired. It was impossible to be otherwise, and to the founders who have had opportunities to make mixtures by following chemical formulæ, the surprise is that we did not receive more censure than we did. It is wholly out of the question for any one to tell correctly what "grade" of iron, pig iron will give when remelted, by judging of its fracture. To assist in demonstrating this fact, analyses of three pieces of pig metal are given in Table 21, and partial cuts of same are seen in Figs. 52, 53 and 54, pages 270 and 271.

TABLE 21.—CHEMICAL ANALYSES OF PIG SPECIMENS.

Fig.	Silicon.	Sulphur.	Manganese.	Phosphorus.
52	.98	.015	.30	.092
53	1.82	.018	.35	.096
54	3.30	.017	.34	.080

The author has numbered the above irons from the appearance of their fracture and not from the chemical analysis, as an iron 3.30 (Fig. 54) in silicon with sulphur as shown would prove a good No. 1 iron when

FIG. 52.—NO. 1 IRON BY FRACTURE, BUT NO. 3 BY ANALYSIS.

remelted, but the fracture would assert it to be a No. 3 iron. One not knowing the analyses of these three specimens would, in judging their grade by fracture, say that the Fig. 53 iron was more like a No. 4 and that the low silicon iron (Fig. 52) in the foregoing Table would make a very soft casting, as to all appearances its fracture looks high in graphitic carbon or silicon, its large, open grains being its deceptive quality. It will be seen by an examination of the chemical properties of these three specimens that they are

FIG. 53.—NO. 4 IRON BY FRACTURE, BUT NO. 2 BY ANALYSIS.

FIG. 54.—NO. 3 IRON BY FRACTURE, BUT NO. 1 BY ANALYSIS.

practically all the same, excepting in the silicon contents. A blast furnaceman would tell us that the deceptive appearance of these samples is mainly due to the irons being "hot" or "cold" as the iron runs from the furnace to the pig beds, as well as to the conditions which permit their cooling fast or slowly. The author could present any number of specimens

No. 1. No. 2. No. 3.

which would be as deceptive to the eye in judging the grade of the metal by fracture, to illustrate that we cannot be guided by the appearance of the fracture of a pig, as in the above examples.

By the appearance of its "face," or the side cast uppermost in the bed, some furnacemen claim they can guess the chemical properties of pig metal. If it has a shrunken or settled-down appearance, so as to make it concave on its face side, as seen at Figs. 52 and 53, and the same is of a close, smooth character, as seen at No. 2, Fig. 55, it is said to generally denote that it is low in silicon and high in sulphur. If it is smooth on its face and not sunken, it is generally accepted as being high in silicon and low in sulphur. If it is called "pitted," or has its face full of little holes running into the body of the pig from one-eighth to one-half inch in depth, similar to illustration seen at No. 3, Fig. 55, it is then said to be very high in sulphur, with a tendency to being low in silicon, although in some cases it may be high. If it is of a character called by some "velvet," by others "moss-back," similar to that seen at No. 1, Fig. 55, it is said to be the best evidence of silicon being high and sulphur low, so as to be a good No. 1 iron and present a good, open-grained fracture when remelted, and it is claimed that it is very rare to find an iron truly a No. 2 exhibiting such a quality. How closely an expert furnaceman came to guessing the true chemical composition in selecting the specimens shown at Nos. 1, 2, 3, Fig. 55, can be told by the following chemical analyses (Table 22) taken from each of the respective samples:

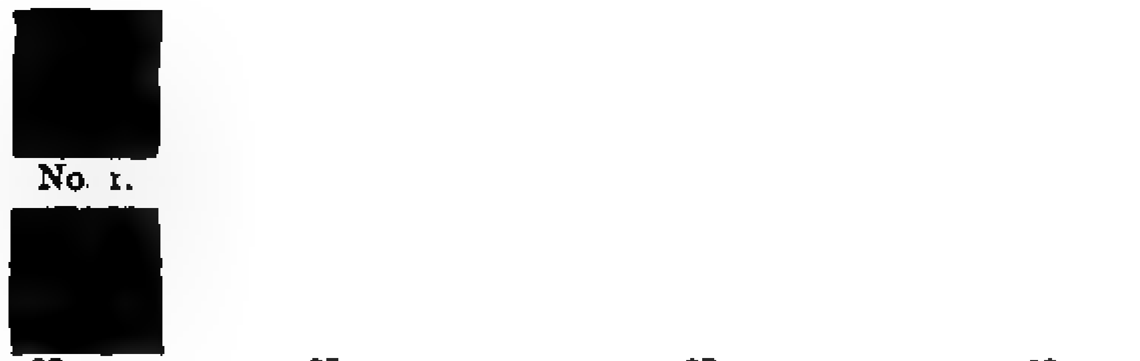
TABLE 22.—CHEMICAL ANALYSES OF PIG SPECIMENS. (FIG. 55.)

	Silicon.	Sulphur.	Manganese.	Phosphorus.
No. 1.	1.43	.043	.34	.105
No. 2.	1.26	.029	.38	.098
No. 3.	.59	.043	.31	.100

It can be seen by the above analyses that the guesses made on their chemical qualities were not very far from being correct, but the author would here say that he has seen all these evidences prove very deceptive in judging iron, even by the appearance of its face; but, taken as a whole, it is much safer to be guided (if we must guess at chemical qualities) by the face of a pig than by its fracture.

When we remelt iron its true character is brought out, so that its grade can be definitely fixed, a point which cannot be better demonstrated in print than by a study of the test bars seen in Figs. 56 to 63, pages 274 and 275. These are photographic views of test bars cast from metal used in actual practice for making guns, chill-rolls, car-wheels, heavy and light machinery, stove plate and sash-weight or "white" irons, selected from about 100 tests, comprising one-half-inch square, one-inch-square and one-and-one-eighth inch round test bars, a complete record and deductions from which are given in Chapter LX. A study of these specimens or cuts will show how the metal is best permitted to have its carbon evolve uniformly in the graphite form by the use of the round test bar, hence showing this to be the best form which we could adopt for obtaining knowledge of the relative qualities in cast iron. It will be seen that by the use of the one-half-inch square bar with weak iron, the carbons remain

FIG. 56.—GUN METAL. SILICON 1.19; SULPHUR .055.

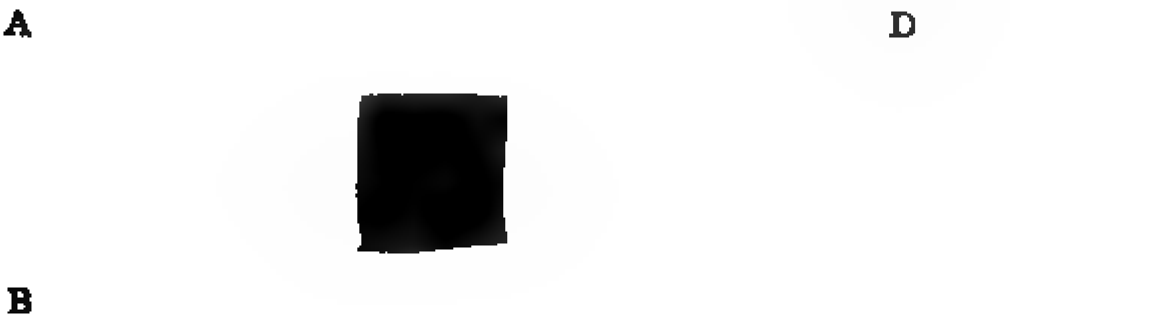


No. 1. No. 2. No. 3. No. 4. No. 5.

FIG. 57.—CHILL ROLL. SILICON .77; SULPHUR .058.

No. 6. No. 7. No. 8.

FIG. 58.—CAR WHEEL IRON. SILICON .66; SULPHUR .127.



No. 10. No. 11. No. 12.

FIG. 59.—HEAVY MACHINERY IRON. SILICON 1.50; SULPHUR .110.

No. 14. No. 15.

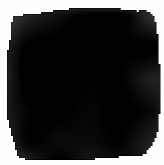
FIG. 60.—LIGHT MACHINERY. SILICON 1.83; SULPHUR .078.

No. 18. No. 19. No. 20. No. 21.

FIG. 61.—STOVE PLATE IRON. SILICON 2.59; SULPHUR .072.

No. 22. No. 23. No. 24. No. 25.

FIG. 62.—SASH WEIGHT IRON. SILICON .180; SULPHUR .138.



No. 26. No. 27. No. 28.

FIG. 63.—SULPHUR TEST.

No. 29. No. 30.

mostly in the combined state, and when used for strong iron, its body becomes "white" or crystalline. In the one-inch square bars the corners, as may be seen, are much deeper in combined carbon or dense in grain than on the flat surface, as seen at A B, Figs. 58 and 59, and instead of its skin or shell being an even thickness or of a uniform texture, as seen in the round bars at D and E, Figs. 58 and 59, it is very irregular. Furthermore, although the square bars are of about the same area as the round bars, still we find the latter has the greatest body of metal in the graphitic form.

Complete analyses of all the specialties here exhibited in combination with others are presented in Chapter XL. These will assist in defining the percentage of chemical properties best to exist in an iron or mixtures to secure the various physical conditions and qualities desired in castings at the present day. Cuts Nos. 29 and 30 illustrate the affinity of iron for sulphur, being the bars described in Chapter XLIII., in which sulphur or brimstone was placed in the ladle after No. 30 had been poured. The white ring at H, No. 29, shows the hardening effect of sulphur. Further data relating to the subject of this Chapter can be found in Chapters XL. and LX.

CHAPTER XXXIII.

PURCHASING PIG IRON BY ANALYSIS.

Moulders or foundrymen should grasp, as a drowning man would a straw, any factor which can assist in lessening the many uncertainties and risks they are compelled to run in their labors to attain certain results in the production of castings, for when we have done our best, we can then have enough to give us cause for loss, worry and trouble. Often has the author, in noticing shipments being made of pig iron, thought to himself, "What a carload of trouble that may make for the founder and furnaceman!" How often does the founder receive iron that causes him losses and poor work, and results in his having contention with the furnacemen and often withdrawing his trade, which could have been retained and the founder have suffered no loss had both parties only realized more the benefit to be derived from study and practice in being guided by chemical analyses or physical tests of remelted iron.

In purchasing pig metal, all that is required of the founder, aside from proper mixing, is to state the chemical or physical qualities which he may desire the furnaceman to furnish, and then let the iron maker "fill the bill" and furnish a card with each "cast" or car of metal, stating its chemical qualities. The author is well aware that at the present time there are but

few founders, comparatively speaking, who are able to tell a furnaceman intelligently what they should have or wish, by analysis, but he trusts that this work may greatly assist in putting an end to tolerating such lack of intelligence on a subject with which the founder should be as familiar as with the tools used in his own shop, or the conditions involved in making a mould. A study of this work should soon cause the moulder or founder, who now looks upon chemistry as something beyond his comprehension, to talk as intelligently and fluently about silicon, sulphur, phosphorus, the carbons, etc., as he now can about sands, ramming, venting, gating, "blow-ups," etc. The grand point about all this is the practicability of its achievement by any ordinary mind that will make any effort at all to master the art. Our foundry is virtually surrounded with makers of pig iron and their chemists. One blast furnace is but about 300 feet from our plant, and to illustrate the method followed at our foundry in receiving pig metal, the following is appended: In receiving iron from the furnace close at hand, small buggies, holding about three tons at a load, are pulled by a little locomotive to our elevator, which then delivers the pig metal on a level with the charging floor, upon which the loaded buggies are then pulled and the iron taken from the same and placed in piles, as described on pages 291 and 292.

With every buggy load, a duplicate of the following card is filled out and delivered to the hands of the boss "cupola charger:"

....

Date ....

Weight.. No. ....

ANALYSIS.

....

Silicon.	Sulphur.	Manganese.	Phosphorus.

"Date" tells the day of delivery, "weight" that of each car, a total of all the cards, the amount received daily; "No." was at one time intended to state the "grade" of the iron, but experience with chemical analyses has led us now to wholly ignore this factor. If we desire to obtain a strong, soft casting, we care but little what grade the iron appears by fracture or how close its grains, if the chemical properties will only read what we desire of them. By the above system we know the chemical analysis of all iron that goes into our cupola. To ascertain what we get out of our cupola, we take physical tests, combined with the analysis of silicon and sulphur, and occasionally other metalloids, as shown by the following two Tables, Nos. 23 and 24. The tests given in this case are from four single bars cast on end taken from a heat of about 50 tons. The mixture charged was all pig (excepting about 5 per cent. shop scrap), ranging from 1.30 to 2.00 per cent. of silicon, and from .020 to .040 in sulphur:

TABLE 23.—PHYSICAL TESTS OF "HEAT" TAKEN SEPTEMBER 14, 1896.

Rotation tests in strength.	Fluidity	Contraction.	Deflection.	Transverse strength in lbs.	Chill.	Diameter of test bar.	Strength per sq. inch in lbs.
1	2⅛"	.135"	.140"	1,955	8/64"	1.143"	1,907
2	2⅝"	.130"	.110"	1,625	6/64"	1.136"	1,604
3	1⅛"	.128"	.120"	1,520	5/64"	1.130"	1 515
4	2¼"	.124"	.150"	1,495	4/64"	1.142"	1,459

REMARKS.

The four test bars showed a perfect, solid fracture. The strongest test bar was the last cast and the weakest bar at the second pouring.

[Signature of Tester.] THOS. D. WEST.

TABLE 24.—CHEMICAL ANALYSIS OF STRONGEST TEST BAR.

Silicon.	Sulphur.	Combined Carbon.	Graphite Carbon.	Phosphorus.	Manganese.
1.20	.079	.094	2.67	.089	0.40

CHEMICAL ANALYSIS OF WEAKEST TEST BAR.

Silicon.	Sulphur.	Combined Carbon.	Graphite Carbon.	Phosphorus.	Manganese.
2.15	.060	.79	2.75	.091	.37

[Signature of Chemist.] D. K. SMITH.

We have an especially arranged book for our office in which a record of the physical and chemical qualities can be recórded, to enable us to work intelligently in making formulæ for mixtures and obtain a record of the chemical or physical qualities of our castings, and from which we can also find the exact percentage of loss in silicon and the increase in sulphur of any "heat."

If the iron comes by rail from foreign furnaces, it is

placed in piles in the cupola yard according to its class and analysis; then when wanted it is transferred to the buggies mentioned above and conveyed to the cupola staging and handled the same as described in the case of the iron delivered by the locomotive. To learn what is obtained in our castings we have analyses made by furnace chemists in our neighborhood. It does not follow that a founder, to work by or utilize chemistry, must employ a chemist in his foundry, for from a study of this work it will be very evident that with the aid of the analyses furnished by the blast furnaces in the delivery of their pig metal, any one can intelligently adopt chemistry as a guide to assist him in making his mixtures of iron; and in order to find out what is obtained in his castings at any time, outside chemists can make analyses for him.

CHAPTER XXXIV.

THE GRADE OF AN IRON.

It has been claimed that to have a knowledge of the silicon contents of pig metal was all-sufficient in making mixtures; also that if the silicon contents of a casting were known, the contraction could be defined. The author takes issue with such a doctrine and can only account for its being thus advocated on the ground of inexperience in general founding, especially in the heavier branches.

There are five elements in iron affecting its character: Sulphur, silicon, carbon, manganese and phosphorus. It takes less of sulphur than any of the other elements to effect a change in the mixture of iron or its contraction, and an increase or decrease in any of the other elements will also produce a change, according as their percentages vary. It is true, we can greatly control mixtures by alteration of the silicon, but in order to do so with the best assurance of success in attaining what is desired, it is also necessary that note should be taken of the sulphur, and in some cases of all the other elements. Owing to the fact that all the metalloids have more or less effect in defining the character of iron or its contraction, it is not practical to guess at the percentage of silicon or any of the metalloids an iron or casting will contain. The author claims that the word "grade" is what should be used

to describe the elements effecting the contraction of iron or casting. It is proper to expect that one might guess the "grade" of an iron where the contraction of test pieces are known, but to define the percentage of silicon on any of the other metalloids by simple knowledge of such contraction is wholly impractical.

The only way to define the silicon or any metalloid contents of any test bar, iron or casting, is by a chemical analysis. The contraction simply assists in telling us the "grade" of iron and nothing more.

As will have been noticed, in various parts of this work, the author refers to "grades" as "high," "middle" and "low." The first implies irons highest in silicon and low in sulphur, such as to give a soft iron; the second, less soft, the third the hardest, as strong irons as those lowest in silicon, etc. For the necessity of recognizing grades when testing or experimenting in iron, see page 460.

CHAPTER XXXV.

SEGREGATION AT FURNACE AND FOUNDRY.*

The uneven distribution of silicon and sulphur in pig metal is largely due to conditions over which furnace managers have at present little control, while with castings, the moulder or founder can, at will or through methods in casting, give rise to a diffusion or segregation of the carbons that could often be prevented were he only aware of the elements which effect such results in castings.

The moulder when turning out a casting having hard or soft spots often finds the word "segregation" very convenient to disguise evil effects of hard ramming, wet sands or ill-vented moulds. Whėn a mould has been properly made and the iron well mixed and melted hot, and poured as it should be, there is generally little to fear in a practical way from segregation in castings that can be charged to the iron or to the mixture, aside from what effects degrees in cooling or casting in a chill can have in causing different proportions of combined or graphitic carbon.

Iron melted or poured dull is much more effective in causing segregation or stratification in castings than

* Revised paper presented by the author to the Foundrymen's Association, Philadelphia, Dec. 4, 1895.

when the reverse conditions prevail. A rammer should never be allowed to hit a pattern, as this causes a hard spot to form on the side of a mould, which for light castings changes the character of the iron at that spot. And the same is to be said where the swab or ill "tempered" sand causes one spot or portion of the mould to be different from another, or the venting is inadequate to the free escape of gas or steam, and again, when pouring may not be steady enough to prevent "cold-shuts," etc. Hard grades of iron are more liable to segregate than soft grades, especially so where the former is melted or poured dull. Light castings are also much more liable to segregate or stratify as to combined or graphitic carbon than heavy castings. The above statements also give additional reasons why test bars as small as one-half inch square or round or any having corners are not the best to be adopted as standards for making comparison of mixtures, etc.

Diffusion, segregation or stratification of the metalloids is much more generally confined to pig metal than to castings. By remelting pig iron, we effect a mixing process, in which the chemical constituents of the castings will be uniform unless they are distorted by means of dull iron, hard ramming, wet sands, ill venting or "chills," as above stated. The elements most liable to segregate are the carbons and silicon. Chiefly with the first named lie most of the phenomena which effect segregation in castings and which are defined simply by one part being higher in graphitic or combined carbon than another. Some have claimed the existence of "sulphur spots" in castings. With iron melted or poured dull, these may exist, but with the reverse conditions the writer has reason to believe

from analyses which he has conducted to experiment with castings in this line, that sulphur will be generally found uniformly distributed throughout a casting that has not been "chilled" from any cause.

In the casting of pig metal, we often find a segregation of the metalloids rarely if ever found to exist in remelted iron which has been poured into sand moulds. One peculiarity in this respect lies in the difference often found in pig metal having its uppermost cast body or face containing the highest sulphur, as shown by the following four samples (Table 25) which the writer secured for this work by the kindness of the chemist, Mr. MacShiras, of Sharon, Pa.:

TABLE 25.—SEGREGATION OF SULPHUR IN PIG IRON.

	No. 1.	No. 2.	No. 3.	No. 4.
Top	.117	.115	.084	.055
Bottom	.083	.094	.070	.047

The above analyses would show that "direct metal" or iron coming from a blast furnace tends to favor the escape of sulphur, but that owing to the top surface of the pig chilling so as to form a crust at an early stage of the solidification of the metal in the pig beds, the sulphur in rising to escape was caught and hence the higher sulphur found in the top body of the pig, as shown.

Silicon is also found to segregate in pig metal. Wherever pig iron shows soft gray spots, analysis will generally show these to be higher in silicon than the surrounding metal. Then again, it has been found that the first metal from a furnace is generally lower in silicon than that which flows afterward, in a manner often so uniform as to show that there is a gradual

increase of silicon in the metal from the bottom upwards as it lies in a furnace before being tapped.

Variations in the working of a furnace make a radical difference in diffusion of the metalloids, especially the silicon, as can be seen by the following analyses, which the writer has also secured for this work through the courtesy of Mr. C. C. Jones, an able, experienced furnace manager, operating two furnaces at Sharpsville, Pa. The pig beds are numbered in the following Table 26 according as they were cast, No. 1 being that farthest from the furnace, receiving the first iron and No. 6 the last:

TABLE 26.—ANALYSES OF PIG BEDS IN A CHANGEABLE FURNACE.

	1	2	3	4	5	6
Silicon	.60	.68	.70	1.00	1.25	2.20
Sulphur	.064	.071	.062	.050	.042	.027
With the furnace normal the result was as follows:						
Silicon	2.18	2.18	2.22	2.23	2.25	2.25
Sulphur	.021	.021	.020	.019	.019	.019

The above analyses of the normal working of a furnace present the best uniform distribution of silicon and sulphur which has come under the writer's notice. As this is a question of no little importance to the founder, attention is called to Table No. 27, on next page, showing the analyses of eight (8) different "casts" giving the silicon contents from the bottom upward, subscribed by Mr. H. Rubricius in *Chemiken Zeitung* and the *Journal of the Iron and Steel Institute, No. 2, 1894*.

The exhibits treat only of silicon and sulphur. With regard to the segregation, etc., of phosphorus and manganese, the only experiments which the writer has observed are those by Mr. A. P. Bjerregaard, com-

mented upon in the *Iron Age*, November 30, 1895. He states his conclusions as follows: "There is often a slight variation in the amount of phosphorus and manganese in the different grades formed in the same 'cast,' but so far, no regular occurring progression variation has been observed. At best, the difference is only a few hundredths of one per cent." The author could present several more tables to show uneven distribution of silicon, etc., but those shown are sufficient to illustrate the necessity for reform in the lines advocated by the author.

When the founder considers that a difference of one-

TABLE 27.—SILICON ANALYSES OF EIGHT CASTS.

Test of pig iron.	1st bed.	2d bed.	3d bed.	4th bed.	5th bed.	6th bed.	7th bed.
1 cast.	1.13	1.15	1.15	1.19	1.33	1.40	1.42
2 cast.	1.38	1.44	1.45	1.60	1.63	1.72	1.79
3 cast.	1.15	1.34	1.43	1.57	2.17	2.18	2.23
4 cast.	1.29	1.50	1.54	1.66	1.82	1.84	1.89
5 cast.	1.95	2.09	2.13	2.45	2.70	2.72	2.76
6 cast.	1.81	1.83	1.84	1.86	1.89	2.16	2.20
7 cast.	2.72	2.74	2.77	2.79	2.85	2.88	2.89
8 cast.	2.46	2.48	2.50	2.53	2.54	2.58	2.60

quarter of one per cent. in silicon and a few hundredths of one per cent. in sulphur will seriously alter the "grade" of his mixture so as to either make his "cast" too soft or too hard, and may often cause him great trouble or loss in the castings produced, he should at once perceive that the uneven distribution of silicon and sulphur which occurs more or less in every "cast" of a furnace is a quality seriously affecting his interests. Especially is this so, when he is aware that the one analysis which may be given is simply an average of the whole, generally taken from the two ends and

middle of a "cast," and that a car of iron may come to him from a "cast," having one portion from one-half to one per cent. higher in silicon than another.

Mr. Rubricius' Table shows that the two ends of a "cast" may vary the whole of one per cent. in silicon. In the comments which he makes on the subject, he says, in effect, that he found such a great difference to exist in the silicon contents of a "cast" that he decided it was not due to errors in analysis, but to an actual variation in the composition of the pig metal at different parts of the pig beds, and that his conclusions were fully confirmed by numerous experiments which he had made to prove their correctness. Mr. Rubricius also affirms that "notwithstanding the large number of experiments made, it was not possible to correlate the initial percentage of silicon and the rate of increase, as iron poor in silicon presents, in some cases, a large increase in silicon in the upper parts. This can only be due to the difference in specific gravity between silicon and iron."

All those who have adopted or recognized chemistry during the past year or two of advancement in founding have still another step higher to take, and that now lies in attaining methods to insure the founder against the evils which come from the present system of accepting one analysis to include a whole "cast." The writer is supported by a large experience with accepting such analyses, in affirming that trouble and losses are sure to follow from such a practice, and that it behooves both the furnaceman and the founder to put their heads together to assist each other in devising and directing methods to eliminate these evils.

It is time attention was being given to this subject

and an effort made in taking out a furnace cast, to pile it or load it on cars in a way that will insure a thorough mixing of the metal, so that when the founder accepts one analysis for a car of iron he will not find that some of his "heats" or parts of them give him trouble or produce a grade of iron in his casting wholly different from that which his analysis should have secured to him or that he had correctly figured was to be expected from the mixtures which he had designed. For systems on "grading," see pages 291, 298.

Casting sandless pigs by means of moving tables of chill moulds, described on page 114, is another step forward to afford the founder greater assurance of receiving uniform analyses in "casts" of pig metal as it comes to his yard or cupola. The first catching of the metal in large ladles, etc., before pouring it into pig moulds, cannot but act as a mixer to cause the one "batch" or "cast" of pigs to be more uniform in their chemical composition. The more the author studies the sandless pig process of casting, the more he has faith that this very recent method of casting pigs will become speedily general practice. Not only has it much to recommend itself to the blast furnace man, but also to the founder, and the more the latter comes to realize that analysis is his guide and not the appearance of fracture in judging of the "grade" of pig metal, the quicker will founders give preference to sandless pigs. Further comments on this subject are found on page 116.*

As we are now in our foundry melting daily from 50 to 70 tons of iron out of one cupola alone, and certain

* This paragraph is added since this article was read at Philadelphia, December 4, 1895.

special analyses are exacted in the castings produced, we are compelled to take every precaution to insure desired results. A loss of 60 tons of castings per "heat" is something few founders would care to maintain many days. Our first practice with this work was to separate the pig metal in distinct piles on the staging, according to variation in percentage of silicon and sulphur, as recorded by the furnace analyses. When charging the iron, directions were given as to the amount to be taken at a time from each pile, in order to obtain the average desired. We will suppose an average of 1.90 in silicon was desired and the only iron we could obtain was some 2.20 and 1.60. These respective grades would be piled independently at different parts of the cupola staging, and when charging, one-half from each would be thrown into the cupola and as evenly distributed as was possible.

Many will agree that this is an excellent plan to assure complete success, and the author thought so at one time, but experience has shown him there are times when this practice leaves a gap for errors. The chances of mistake include the engagement of new men, old ones getting sick or drunk, hot weather playing men out so as to make them neglectful or to use bad judgment in sorting or placing the iron in its proper place on the staging when piling it previous to charging. Experience has taught that wherever any details of founding can be governed by positive mechanical methods of working, they should have the preference every time. For this reason I have lately adopted the following plan as an improvement upon the first, and I am pleased to say it is working very successfully:

In the delivery of pig metal to the stage, wherever two or more distinct grades must be used to obtain the average desired, we now insist upon each varying grade coming to the stage at the same time, on independent buggies, and then instead of piling each grade separately, as was formerly done, they are mixed pig about, in the same pile, of one ton each, so that when charging time comes, there are no high and low distinct iron piles which must be carefully guarded in order that no more of one than the other, as desired, goes into the cupola; but it allows any pile to be used, and if the men then try to make blunders, or ill-mix the iron, as was easily done in the former case, they cannot do so. This latter plan involves no more labor in piling the iron on a cupola stage in "the cool of the day" than the former one, and I know from experience that it is far superior in giving a uniform product in the castings.

The question may be asked: "If we were to receive one portion of our iron one-half per cent. higher in silicon and .02 in sulphur than the analysis calls for, how is any system of piling it on a cupola staging going to remedy the lack of a thorough mixing of a furnace cast?" The only reply the author has is that he is not responsible for the furnace end of it, but believes he has pointed out a line of action to improve furnace methods in piling and shipping iron, as seen on page 299 and in the supplement to this Chapter, and has faith that at least all following the second method described above for the foundry end of the work will find it a decided improvement.

In dull times, when the founder has little use for pig iron and the furnace yards are full and new counties

are sought for, to pile it up for delivery in a "boom" time, the founder can readily get the percentage of silicon and sulphur in one grade of iron which he may want to make the castings desired. It is when a "boom" is well on and the founder has got good use for pig iron that he often finds difficulty in getting just what he should have, and by the scarcity of desired iron often experiences trouble and losses in trying to patch up mixtures. For example, a founder might desire to secure a 2.25 per cent. silicon iron, combined with some special manganese or phosphorus brands, but could only obtain for immediate use a much higher or lower silicon iron, which he would be compelled to average up or mix the best he could to obtain the grade desired.

A point that may well be raised is: what divergence in the extremes of silicon, etc., percentages is permissible without producing ill results. Some have gone so far as to use and advise the practice of mixing ferro-silicon or pig iron containing from 7 to 14 per cent. of silicon with "white" iron to obtain good grades of gray iron castings. The writer is not an advocate of blending such extremes wherever it is possible to avoid the practice. Ten chances to one, more moderate measures will give more uniform results throughout a "heat," and the longer the heats are the greater the necessity for avoiding extremes in the silicon, etc., of the irons making a mixture. It is not practical to be too exacting in this line, owing to the fact that when iron is scarce, the time the founder requires the most, a furnace cannot always on a moment's notice supply all its customers' demands. Nevertheless, those working strictly by analysis in making mixtures of iron

will find it wise to deprecate the plan of utilizing irons in mixtures that vary widely in their chemical composition. I believe steel men have found by experience that a great variation in the sulphur and silicon contents of any two or more irons which may be mixed to obtain an average desired is very objectionable and often injurious to the product.

It is to be understood that this paper in no wise covers the whole question of segregation in cast iron. It is the writer's intention to only call up practical points which confront us all in every-day practice. As a rule, the portion of a casting remaining the longest in a fluid state will, should there be any segregation, contain the greater percentage of the metalloids, unless there is distortion by artificial means, such as "chilling," wet sands and ill-vented or ill-poured moulds.

It is not segregation proper that is of greatest importance at the present hour, but rather that the founder know that the chemical analysis of his iron is uniform throughout a shipment, that he truly receives what the analysis calls for, and that he has methods to mix the iron ready for charging that will best insure the grade desired in castings. Complaints from the founder are sure to be lessened and a greater trade insured to furnacemen, assisting him to obtain a thoroughly mixed iron, before it reaches the cupola. For further information on this subject of buying iron on analysis and getting it to a cupola, etc., see page 277. Following this Chapter will be found a supplement which, on account of the close similarity on points treated, is not made an independent article.

SUPPLEMENT TO CHAPTER XXXV.

The publicity given to Chapter XXXV. by trade papers after its presentation by the author to the Foundrymen's Association, December 4, 1895, was not long in being productive of good results. It attracted such attention that, a few months after its publication, the subject was taken up by the Western Foundrymen's Association, April, 1896, under the head of a topical question entitled, "Irregular Grading of Foundry Iron." In answer to a request from the secretary of the Western Foundrymen's Association, the author sent the following, which is an extract of his letter, and which was also published prominently by leading trade papers:

The founder is sure to find more or less irregularity in the appearance of irons received from any furnace grading their metal entirely by chemical analysis. The fact that iron looks irregular in its grain or fracture is no evidence that it will not come out all right remelted, providing a correct analysis has been given, and it has been well mixed before shipment and is remelted in good, regular order. It is only by chemical analyses, or the regular remelting of pig metal, that the true grade of iron can be defined.

Granting that the query of this evening's discussion has no reference to judging iron by its fracture, the writer must then conclude that the trouble that has been experienced is due to the chemical analyses as given hav-

ing proved incorrect by the test of remelting. The writer knows that present practice is attended with trouble and loss to the founder, and believing the issue should be met squarely and frankly, and that in the end the furnaceman will be benefited, as well as the founder, no one should hesitate to give freely his knowledge and experience on the subject.

The founder who adopts chemistry must have his practice perfected as far as possible in all its details before he can be sure of always obtaining desired results from mixtures in remelting pig metal. There are two evils that can cause a founder loss and trouble. One of these is the furnace practice of only taking one analysis from a run of 24 hours when a furnace is on foundry iron and letting that one determination stand for the chemical properties of the four or five "casts" which the furnace has made that day. It is not to be understood that all furnaces follow this practice, nor is the writer aware that it obtains any more in the South than in the North, but he does know that such practice should not be tolerated by any furnace claiming to grade iron by analysis, and is little better than trying to achieve desired results in remelting, by judging the "grade" of pig iron by its fracture or grain. Every furnace "cast" should be analyzed and the metal of each cast kept separate by itself, when piled in the yard or shipped on cars, so that when the founder receives the iron he has not a chemical guess, but a positive fact to guide him aright in remelting his pig iron.

The second evil that exists is the inattention which furnacemen generally pay to thoroughly mixing a "cast." The general practice is for a furnace to take

samples from each end and the middle of a cast, to obtain the analysis which is to define the chemical properties of the whole "cast," and which is intended to guide the founder in making his mixtures. In the paper which the writer presented to the Foundrymen's Association at Philadelphia, December 4, 1895 (Chapter XXXV.), it is clearly shown how one end of a furnace cast can differ fully one per cent. in silicon from the other end, and also that the sulphur can vary greatly in the two ends of a cast. The founder receiving one analysis from such a cast, if the iron had not been thoroughly mixed, could be deceived one-half of one per cent. in silicon and several points in sulphur. It cannot but be evident that such a practice gives the founder reasons for complaining of irregularity in the grade of irons which he receives from a furnace.

The adoption of chemistry about two years ago by the founder was one reform that has gone a great way toward assisting him in having assurance of obtaining desired mixtures of iron, but another step is now required and that is for the founders to encourage blast furnacemen to devise systems for the thorough mixing of a cast as the iron is being removed from the casting house to be piled in the yard or loaded for shipment. This last reform is as essential as was the first one, before the progressive founder can conclude that the best that modern advancement can insure to him has been put into practice. A founder has good reasons for using all the precautions he can to obtain desired mixtures, as much as the steel maker finds the utmost precision necessary to success in obtaining desired physical properties in his product. There is often much about which the founder is compelled to grope in the

dark, and it behooves him to take as few chances as possible and know, if he can, that each element is within itself correct. An ill-mixed "cast" of pig metal is liable to leave the founder perfectly defenceless in working, and affords an additional element to befog and sidetrack him in determining what was the cause of his failure to obtain the grade which he had felt so confident of securing. Remove this uncertainty and the founder has one less evil to contend with and is placed so much nearer to the goal which all should strive to reach.

Statements were made at the reading of the above article, at the meeting of the Western Foundrymen's Association, April, 1896, showing that furnacemen were actually following methods to comply with the line of reform which the author first advanced at the Foundrymen's Association, Dec. 4, 1895. At this meeting, Mr..D. L. Cobb, representing the Sloss Iron & Steel Co., Birmingham, Ala., stated that his company was having four analyses made of each "cast," instead of only one, which was the general practice. As the author was eager not to let the subject lag and desirous of pressing it forward in order to get other furnacemen interested in following a similar practice, he wrote the following article, which appeared in the *Iron Trade Review*, June 4, 1896, under the head of "Systems for Uniform Grading of Iron:"

Believing the advance inaugurated at Birmingham should be given the fullest publicity, the writer presents this brief memorandum and trusts that others will take the subject under consideration, to further the end so desirable and necessary to be attained.

It is certainly encouraging to see the step taken by

the Sloss Iron & Steel Co., as it will likely influence other furnacemen to strive for the same end, or go one better, so that it will not be long ere all furnaces will have some system giving the founder better assurance as to the analysis of the iron on which he depends so much to give desired results.

While the writer does not wish to discourage the furnacemen from taking any number of analyses of each "cast," or adopting any other plan, he would advocate the following as another method of assuring the founder that the analyses he receives of a "cast" or shipment of iron represents the whole or any part of it:

First: In loading the pig metal at the "casting house," let a sufficient number of buggies be used to convey all of a cast to the point of piling or shipping, before any iron is removed from the buggies.

Second: Have the "iron storers" start at one end of the metal train and each man take a pig off from each car in concerted order, piling the same in regular form. As each man reaches the end of the train of iron buggies, he would return to the starting point, thus giving a continuous circuit of travel by the iron storers until all the train is unloaded and the iron placed in yard piles or distributed over cars for shipment. Such a plan need cost nothing more than that at present followed by furnaces in piling or shipping iron. In fact, if anything, it would be generally more economical. It would guard against any one of the storers shirking duty, as all would have to follow the leader or drop out of the file, and make indisposition to work very conspicuous. This method would insure a most thorough mixing of the cast and thereby make

the one analysis, as at present, generally taken and forwarded to the founder, all sufficient and better in many cases than three or four sub-divisions of piles or analyses for the furnace and foundry to keep track of from every cast or car of iron.

Although this plan differs from that described by Mr. Cobb, the step taken should be heartily approved. And now that the Sloss Co. has led the way, a universal adoption of plans to insure correct analyses being presented, to aid the founder in obtaining desired results from mixtures of iron, should be encouraged by all progressive furnacemen and founders. This is a reform fully as important as that of grading iron by analysis (instead of fracture, as practiced a few years ago), now adopted by nearly all furnaces as the result of continued agitation at the hands of a few and of concerted foundry association effort.

This article was written right after Mr. Cobb's comments were published in the *Iron Age* and the *Iron Trade Review* of April 22, but held back to get an early presentation at some of the foundry association meetings; but owing to their being crowded with previously prepared papers, I had it first published in the *Iron Trade Review*, and trust that other furnacemen will soon be heard from in seconding the Birmingham movement to further aid in lessening the founder's troubles.

CHAPTER XXXVI.

BESSEMER vs. FOUNDRY IRON.

That "Bessemer iron" can often take the place of "foundry," and in some cases prove a better product to make castings with, is a fact which few founders have up to this writing discovered. In the years 1893 and 1894 of business depression, Bessemer pig was selling cheaper than foundry pig. A few founders, who did not require high phosphorus and knew it, took advantage of the low price of Bessemer. Founders never having had an experience with Bessemer pig metal will be somewhat surprised to learn that the best experts cannot tell "Bessemer" from "foundry" by judging of the fracture; nevertheless this is true. It is only by analysis that the difference is to be made known, and that mainly exists in the phosphorus being lower in Bessemer than foundry, as illustrated in Table 20, page 255.

Regular Bessemer ranging from 1.40 to 1.60 in silicon, .010 to .030 in sulphur and about .45 in manganese, can often be well used for hydraulic or steam cylinders, heavy dies, machinery castings, and for gear wheels of one and one-half inch pitch and upwards.

For ordinary machinery castings that average from one and one-half inches up to two inches thickness of metal, Bessemer ranging from 1.60 to 1.90 in silicon would be found to work very well. The author has

used Bessemer 1.85 to 2.00 in silicon with excellent success in making electric street car motor gear wheels. These wheels, as many know, are cast in a "blank" and the teeth are milled out. When first starting in to make these castings it was a "trick" of ours to take a pin hammer and strike upon the teeth of a spoiled wheel until the tooth would flatten out as if one were pounding a piece of wrought iron. This was partly due to low phosphorus, causing the iron to possess a malleable toughness. Bessemer containing from 1.95 to 2.25 silicon would make an excellent iron for all castings such as ordinary weight of lathes and planers. For heavy punches and shears it would be well to have the iron range from 1.10 to 1.30 in silicon, with sulphur about .030 in the pig. It is to be remembered that owing to Bessemer being low in phosphorus it is not as fluid a metal to "run a mould" well as foundry iron. Nevertheless, it can be melted "hot" enough to run castings as thin as "stove plate," if the liquid metal is not retained too long in the ladle or has not to run up too far in a mould, or a long distance from the "gate;" but it is not recommended for such light work.

A founder can utilize common scrap with Bessemer pig metal for all work above stove plate thickness, as in this respect sufficient silicon can be obtained in "Bessemer," as well as in "foundry," to soften scrap, and thus often assist in cheapening a mixture. Silicon does not, as a general thing, go as high in Bessemer as in foundry. When silicon exceeds 2.50 per cent. in Bessemer, it is generally called an "off Bessemer," the same as when it exceeds .10 in phosphorus. To be over 2.50, the limit for silicon in regular Bes-

semer, is not so objectionable to steel men as it is for the phosphorus to be over .10. Steel works will often accept Bessemer over 2.50 in silicon, but seldom accept phosphorus over .10, unless the iron is used to make steel by the "basic process," a method by which phosphorus can be greatly eliminated from the iron by reason of qualities in the lining having an affinity for phosphorus. Bessemer iron, to be such, in the regular sense, must not have over one-tenth of one per cent. of phosphorus, which is a small quantity compared with one per cent. often utilized in foundry iron in order to give the molten metal good life and fluidity.

It is to be understood that in all the mixtures shown on pages 301 and 302 the sulphur is not to exceed .030 or the manganese .55 in the pig; if it does, then higher silicon will be necessary in proportion to their increase; also, that no scrap is intended to be mixed with the percentages of silicon given. Should it be desirable to mix scrap with the pig, which, of course, if not Bessemer scrap, would raise the phosphorus, to take the mixture out of the category of Bessemer iron, and in either case with any kind of scrap, it would call for an increase of silicon in the pig metal, so as to prevent the mixture from producing too hard a "grade," as defined in the last paragraph, page 302. For further notes on Bessemer, see pages 524 and 535.

CHAPTER XXXVII.

CHARCOAL vs. COKE AND ANTHRACITE IRON.

The past advancement in utilizing chemistry in making mixtures of cast iron has, among other changes in founding, resulted in causing some firms to make castings of various types from coke irons, whereas for years past it has been thought that charcoal was the only grade admissible to be used. It is no reason because malleable iron founders and some car wheel and chill roll makers have discovered that coke and anthracite iron can be made to answer their purpose that charcoal iron is sure to pass into oblivion.

A peculiarity between "Bessemer" and "Foundry" iron lies in the fact that one cannot be told from the other by yards, single pigs or piles, in judging them by fracture. This cannot be held to be true of charcoal vs. coke iron. If there were two yards of pig metal, one being charcoal and the other being all coke or anthracite iron, any one at all familiar with such irons can generally tell the class of iron each yard contains. We may occasionally see single pieces or piles of coke or anthracite pig iron which will resemble charcoal so closely as to make it difficult to decide its true class, but, taken in a general way, charcoal iron is distinguishable from coke or anthracite iron.

The greater the temperature in a blast furnace, the more silicon can iron absorb. The lower heat derived from charcoal furnaces causes less silicon to be taken up than with iron in coke or anthracite furnace. From this circumstance, combined with the fact that charcoal fuel is free from sulphur, we find that charcoal iron generally contains little or no sulphur, with low silicon. The more general uniform workings of charcoal over coke furnaces and absence of sulphur in charcoal iron leaves much less for the other elements, silicon, manganese, phosphorus, etc., to cause radical variation in the size of the grains, and hence we find, as a general rule, charcoal iron to be more uniform in grain than coke or anthracite irons.

The greater strength and homogeneity of charcoal over the present coke or anthracite iron, also in its possessing little or no sulphur, will, in the author's estimation, forbid its expulsion from the market. There are certain kinds of work for which charcoal will generally prove superior over other irons. These can be classed in the following order: (1) chilled work, (2) gun manufacture, (3) hydraulic and steam cylinder castings. Heavy gearings and large castings require high strength combined with softness sufficient to admit of finishing. Coke iron is now used in nearly all the specialties, but where it is intended to replace charcoal, special care should be exercised in watching the sulphur contents in order to get them as low as possible. Where the coke or coal fuel and ore are very low in sulphur, coke or anthracite iron can be made which may often answer many purposes of charcoal pig. Charcoal pig iron, on the whole, is poorer in silicon and phosphorus, as well as sulphur, than a coke or anthracite pig metal.

Charcoal fuel contains no sulphur, and if the ore and flux are likewise free from it, an iron will be obtained free of sulphur, something which cannot be said of coke or anthracite iron. Let charcoal iron be melted in an "air furnace," instead of a cupola, where the iron must be mixed with coke or coal, and it can then clearly demonstrate its superiority over coke or anthracite iron. To melt charcoal in a cupola greatly impairs its superior qualities and brings it largely on a level with coke or anthracite iron. Coke or anthracite will often answer well for an approximation, but to obtain the very best mixture for chilled work, guns, etc., charcoal iron will ever remain king, when melted in an air furnace, unless modern advance arranges to eliminate sulphur, etc., from metal to "refine" the iron before it is cast into pigs in a manner to be relied upon one "cast" from another, or after being re-melted in cupola. Should such a method as that of Mr. Uehling, page 125, prove thoroughly practical and not too expensive, it is hard to predict at this time how far it may not go in causing coke to displace charcoal iron.

The above word "refine" means to lower the metalloids so as to give a greater percentage of "pure iron" or metallic iron, sometimes called, which can add strength to cast iron. This is not saying, the more pure iron the greater the strength, for, as shown on page 000, and test No. 7, page 320, there is a limit to its increase being beneficial. It is regulated in adding strength, to a degree, by varying percentages of the metalloids, silicon, sulphur, phosphorus, and manganese, similarly as they affect the combined carbon. For analyses of charcoal iron, see pages 320 and 536.

CHAPTER XXXVIII.

CHEMICAL FORMULA IN MIXING AND MELTING SCRAP IRON.

Scrap iron, as a general thing, is a product which has been ré-melted one or more times, and hence must fairly show its true grade in a clean fracture. The advent of chemistry in founding will naturally cause some to ask: is it not necessary to know the metalloids in scrap iron as well as in pig metal in order to obtain desired results from mixtures? It is, of course, well to have analyses of scrap the same as with pig metal, wherever this is practical, but owing to the fact that scrap generally comes to the founder in a promiscuous manner, often a little of everything, working by analysis becomes largely impractical, either as to obtaining actual analyses or attempting to guess the chemical properties. In reality, it is not practical to define any of the metalloids in scrap iron by guesswork. About the only practical plan which the author can suggest is to consider and class scrap in the order of "grades," by numbers: as, for example, build an imaginary base to define "grades" from the texture and grain which would be obtained by the remelting of pig metal, say, containing 1.00, 2.00, and 3.00 per cent. of silicon, respectively, with sulphur supposed to be constant at .030 and phosphorus and manganese as gen-

erally found in their foundry iron, in all the three mixtures. By such a method any founder having had experience in following chemistry to any degree will soon know what "grade" the above mixtures of pig metal would give were they poured into castings ranging from stove plate up to bodies six inches thick, and then, when sorting scrap in "grades," they would simply be contrasted with the "grade" produced by the imaginary pig mixture which had been taken to define a base for a grade desired. By following such a system as this it is very evident that the grading of scrap iron could be reduced to a very satisfactory point, in all work where it is economical to utilize scrap iron.

As a general thing, founders are desirous of utilizing all the outside scrap possible in mixture with pig metal, because it generally can be bought for less than pig iron. With work that admits of a good leeway in the grade or mixture obtained, such as floor plates, furnace castings and heavy machinery not requiring much finishing, etc., scrap iron can often compose the greater part of the mixture, especially so if silicon pig has been used to soften the scrap. In the case of stove plate or light machinery castings requiring much finishing, much more care is necessary in attempting to use much outside scrap iron. The same is to be said of chilled work where definite results are to be insured. In many chill work specialties it is often very poor economy to adopt the practice of utilizing any outside scrap; but, of course, shop scrap, such as gates, etc., every shop must work up in mixture with its pig metal. An all-pig mixture, of which a correct analysis has been given, enables the founder to be much more positive in obtaining desired results than

where he attempts such results by mixing promiscuous scrap with the pig metal. The loss of a few castings ofttimes more than counterbalances the difference in the price of pig and scrap metal, and in some cases, if the question of gross tons in pig metal is considered, the difference will be found strongly in favor of the straight pig mixture, as against that of a combination of scrap, which is generally sold in net tons.

In grading scrap that shows evidence of having been chilled, such as that in car wheels, rolls, dies, crushers, plows, etc., it is as essential to consider the texture of the grey body of the casting or scrap as it is that of the depth of the chill, for the reason that the depth of the chill part can be deceptive in denoting the true grade of the iron, from the fact that degrees in the pouring temperature of metal, as well as the thickness of the chill to the limit used for forming the chill part of the casting, has an effect in forming the depth of the chill, elements more clearly defined in Chapters XLI. and LVI.

About the worst class of scrap to pass judgment upon, in an effort to grade it, is that coming under the head of "white iron." Where bodies of scrap are all white, the silicon contents may, in castings say from "stove plate" up to two inches thick, contain silicon all the way from .50 up to 1.50, and in more massive castings than three inches thick, it is generally safe to conclude that the silicon can range from .10 up to 0.40, with sulphur in any of these thicknesses ranging all the way from .050 up to .200. As a basis to guide the founder in an effort to grade such irons for mixture with softer metals, it can be taken for granted that the sulphur is generally very high and the silicon low

in all white scrap iron as it comes to the foundry.

Burnt iron can be said to be the most undesirable class of scrap for a founder to handle, and there is a doubt in the author's mind that it pays any founder in the end to experiment with it, for making anything other than castings like sash weights, for, as a general thing, its loss in weight by re-melting will range all the way from 30 to 95 per cent. It is a very indefinite quantity to judge of as to its chemical composition. It is safe to say it will greatly injure other irons when mixed with them in raising the sulphur and lowering the silicon so as to produce a "white iron," and will often spoil many castings.

Any intelligent foundry laborer should, with a little training, be able to select and pile scrap according to its grade. As some would prefer an approximation for the silicon and sulphur contents of grey scrap, the author would say that iron ranging from stove plate up to one inch in thickness may be considered as an approximate equivalent to remelted pig metal that has its silicon ranging from 1.50 up to 2.00 per cent., and for bodies above one inch thick up to three inches thick from 1.00 up to 1.75 in silicon, sulphur in all cases to be considered as constant at about .06. Above three inches in thickness a grey open fracture can range in silicon all the way from .75 up to 2.50, and the grading of such heavy bodies generally requires a more skilled eye than with scrap, which might be under three inches in thickness; but practice would soon bring one to an approximately close guessing of the grade of heavy, as well as light bodies. Where scrap comes to the foundry yard in the form of complete castings, which the founder will have to break, he can, by "siz-

ing up" the general proportion and shape of the whole casting, judge much more readily of the "grade" in the massive parts than if it came to his yard in a haphazard form.

We are compelled to analyze pig metal (as shown on page 269) simply because it is deceptive in showing its true "grade" to the certainty that scrap iron will admit of, on account of its being a re-melted product. If any wish to grade scrap by the latter plan suggested in this Chapter of estimating the chemical qualities, it is not necessary to follow a silicon formula for a base any more than it would be to accept sulphur; but owing to the fact that silicon is the element generally largest in grey castings, excepting the carbon, it is, as a rule, best to accept silicon as the first base, as it affords a larger range of figures in guessing the percentage which, if not close to the actual silicon contents, cannot so greatly result in injury as it could in the case of an error if a guess of the sulphur, contents, etc., erred much. As scrap with many founders constitutes a third and often two-thirds of their total mixture, this Chapter cannot but be of benefit to any who may be desirous of conducting their mixtures of scrap iron with the best possible assurance of obtaining desired results.

CHAPTER XXXIX.

EFFECT OF FUEL, FLUXES, TEMPERATURE AND HUMIDITY OF BLAST IN RE-MELTING CAST IRON.

It is as important to possess knowledge of changes caused by re-melting iron as it is to know the chemical constituents of the iron before it is charged into the cupola. For the past four years the author has followed closely the records which were daily compiled at our foundry of the chemical properties in the iron charged and also the product received from the cupola in "heats" ranging from 40 to 70 tons. The following Table, No. 28, compiled from one week's melting in this foundry, with coke about .80 in sulphur, will serve to illustrate the change due to silicon and sulphur in re-melting iron:

TABLE 28.—DECREASE IN SILICON, AND INCREASE IN SULPHUR, BY RE-MELTING IRON.

Silicon in pig.	Sulphur in pig	Silicon in castings.	Sulphur in castings.	Loss in silicon.	Gain in sulphur.
1.93	.022	1.77	.040	.16	.018
1.84	.016	1.65	.046	.19	.030
1.78	.031	1.58	.056	.20	.025
1.52	.029	1.39	.061	.13	.032
1.46	.027	1.33	.056	.13	.029
1.28	.021	1.10	.067	.18	.046

The increase in sulphur in re-melting is dependent

upon the amount of sulphur in the fuel, the silicon and manganese in the iron, the flux and the heat in the cupola. An increase of the sulphur in the fuel or flux will cause a corresponding increase of sulphur in the iron; while the less fuel used and the better a cupola is fluxed or "hot iron" produced, the less sulphur will the re-melted iron contain.

The reduction or oxidation of silicon is greater the higher the blast pressure and also the hotter the iron is melted. In a general way, it can be said that silicon is reduced from one to three-tenths of one per cent. and sulphur increased from one to six hundredths of one per cent., where the fuel is not over .80 in sulphur. The author has, in a few rare cases, found the silicon to be but very little reduced, but never found a re-melt where the sulphur was not materially increased. The increase of one part of sulphur can often neutralize the effect of six to twelve parts of silicon, and hence, owing to the increase of sulphur being so powerful in neutralizing the effects of silicon, it is very essential that all conditions influencing the increase of sulphur should be guarded and controlled so far as practical, in order to be best assured of obtaining any desired results in the castings.

The changes due to manganese in re-melting iron are toward its reduction and the elimination of sulphur, thereby often causing iron to soften by increasing manganese in a mixture. The more manganese iron contains the less the increase of sulphur, owing to the affinity manganese possesses for carrying off sulphur in the slag.

Phosphorus may be called a "sticker," as when once absorbed by iron it cannot be easily eliminated.

In re-melting iron, whatever phosphorus the fuel or flux may contain will largely go to the iron, and hence phosphorus has a tendency to be increased every time iron is re-melted. Its influence in effecting changes in the other elements is to favor the reduction of silicon, sulphur and manganese, owing to the quality of phosphorus which causes iron to have greater fluidity and life.

Total carbon is, as a general thing, slightly affected in re-melting. It may be increased or decreased, this being partially dependent upon the amount of fuel used and the temperature in the cupola. Excessive fuel and a high temperature have a tendency to slightly increase the total carbon, whereas little fuel and a low temperature may decrease the carbon. It is also, to some degree, dependent upon the silicon and manganese present. The former retards, while the latter promotes the increase of carbon.

Combined carbon with the silicon above four per cent., and sulphur not over .01, may sometimes be slightly reduced. After silicon has decreased to 4.00 with the sulphur above .02, every re-melt will surely increase the combined carbon until the silicon is so decreased and the sulphur increased that "white iron" will be produced, giving an iron which may have its carbon almost wholly in a combined form.

Graphitic carbon is increased accordingly as combined carbon is decreased, and the elements best calculated to promote its formation are high silicon, medium phosphorus and manganese combined with low sulphur.

In a general way it can be said that with iron melted in the cupola, the silicon, manganese and graphitic carbon are decreased, while the sulphur, phosphorus and combined carbon are increased.

The higher the silicon and phosphorus, the higher the temperature required to melt the iron. For this reason, hard "grades" will melt more easily or become fluid with less heat than soft grades of iron.

The above treatise is to be understood as dealing with cupola practice only; and as the author has had no opportunity of late for experimenting with results to be derived from re-melting iron in an "air furnace," he cites the following extract from Sir William Fairbairn's report before the British Association of Science on the effect of re-melting iron in an "air furnace" eighteen times, in which he describes the action of re-melting as follows:

Phosphorus increased from 0.47 to 0.61. This was probably due to loss of metal by oxidation. Manganese decreased from 1.75 to .12. This would tend to improve the metal during the earlier meltings. Silicon was reduced from 4.22 to 1.88. The first effect of this reduction was to produce softer metal and lower combined carbon, since silicon was present in quantity in excess of that necessary for the softest metal. On further reduction of silicon the metal became stronger and harder. But in these experiments the reduction was not carried sufficiently far to cause any deterioration due to sufficiency of silicon. Sulphur increased from .03 to .20, and this is one of the most important changes which took place, the increase in sulphur tending in the same direction as the loss of silicon, viz., the production of high combined carbon. The combined carbon increased considerably after the eighth melting, ultimately reaching to over two per cent.

By Fairbairn's experiments we find that the results of re-melting in an air furnace are partly similar to those from a cupola, and in both cases that this is a subject as necessary to be understood in order to obtain desired ends as is that of knowing the chemical properties of the iron before it is charged.

There have been experiments conducted in order to

observe whether there would be any difference in the strength of iron taken from the beginning, middle, and end of "heats," where a uniform mixture was used throughout a heat. Results received affirm that some would obtain the strongest test at one part, while others would receive them from another part of a heat. In this practice the author cannot conceive of any uniformity being obtained unless the management is such as to insure a like temperature and fluxing at every part of a "heat," and in this quality generally lies the secret of the difference between one founder and another. One may have a cupola giving the hottest iron at the beginning of a heat while another will obtain this at the middle or the end. According to the variation of temperature when remelting iron, so is the combined carbon affected by changes in the silicon, sulphur and manganese; and taking this view of the subject the author believes that all can understand why we find founders disagreeing in such tests.

As the humidity of the air can, to some extent, produce changes in the smelting or melting of iron, one heat from another, the author appends the following excellent article written by Mr. A. Sorge, Jr., M. E., in the *Foundry*, April, 1896:

That variations in the humidity of the atmosphere and its temperature do affect the operation of melting iron in a cupola, will be conceded by foundrymen who have observed the difference in melted iron on different days. Iron is liable to be cold and sluggish with the same charges of fuel on cold and moist days, while it is hot and fluid on warm and bright days.

It is therefore reasonable to look for one cause of poor melting to the atmospheric conditions. Let us assume that we are melting at a ratio of eight iron to one coke on an ordinary bright day,

when the temperature is 62 degrees F., and the percentage of moisture in the atmosphere about 0.52 per cent., which is about the average in Chicago.

It has been found by experience that about 33,000 cubic feet of air are required to melt 2,000 pounds of iron in ordinary cupola practice. This air will weigh about 2,500 pounds, and is heated originally to a high temperature by the ignited coke before it becomes active in supporting further combustion. Also any moisture contained in this air must be brought to the temperature of the gases which escape from the top of the cupola. This latter temperature varies greatly, but will be in the vicinity of 500 degrees F. for good practice.

If the temperature of the atmosphere should drop to 32 degrees F., this means that the air delivered to the cupola must be heated 30 degrees, so as to bring it to the normal. The specific heat of air being taken at 0.238, we obtain $2,500 \times 30 \times 0.238 =$ 17,850 B. T. U. as the amount of heat required to do this work, or theoretically about 1⅜ pounds coke would be consumed if we obtained perfect combustion. The fact being that the actual amount of heat obtained from the combustion of coke in a cupola is only about ¼ of the theoretical, it follows that the actual coke consumed for this extra heating is about 5½ pounds, which should be added to the usual amount of 250 pounds per ton of iron, making 255½ pounds, or a ratio of about 7.8 iron to 1 coke.

If, at the same time, the air is charged with particles of moisture, as when a heavy snow-storm is in progress, it will contain, say, about 4-10 per cent. of frozen water. In the 2,500 pounds total this will amount to 10 pounds, which must be transformed into vapor at 500 degrees F., involving 14,740 B. T. U. of heat. On the other hand, this amount is reduced by the heat expended in raising the average vapor of 0.52 per cent. in 62 degrees air to 500 degrees F., which amounts to 2,714 B. T. U., leaving an extra amount of 12,036 B. T. U. consumed by the snow, which will again require about 3.6 pounds coke.

The total coke consumption in the above case will therefore be 259.1 pounds per ton of iron, or a ratio of 7.7 iron to 1 coke, in order to deliver the melted iron in the same condition as on an ordinary day. In other words, an additional fuel consumption of a little over 3.6 per cent. is needed under the above conditions,

so as to obtain the iron in the same state of heat and fluidity as when ordinary dry air at 62 degrees is used.

On the other hand, a higher temperature and greater dryness of the atmosphere will operate in permitting the amount of fuel to be reduced.

In the above figures I have assumed ordinary conditions, but the actual practice must be carefully taken into consideration wherever it is desired to figure out the effects in any particular case, and it is well worth a foundryman's time to go into this question, figuring out the extra amounts of coke needed under various conditions of moisture and temperature, when a short observation of an ordinary hygrometer and thermometer will enable him to avoid the risk of cold and sluggish metal on any day.

Mr. W. H. Fryer has shown and published the statement* that air containing 0.8 per cent. of moisture will introduce about 89.6 pounds of water into a blast furnace per ton of iron made, using about 2,250 tons of coke for fuel. This is a factor the founder should not lose sight of. When air is moist, it is to some degree practically the same thing as fuel being water-logged. With such wet fuel, as many founders know, a larger percentage is necessary to re-melt iron than if the fuel were perfectly dry, and also that this can cause trouble much more readily in the line of "bunging up" a cupola. For further information of the effects of humidity, see Chapters XII. and XIII.

* Journal of the Iron and Steel Institute, Vol. II., 1887.

CHAPTER XL.

CHEMICAL CONSTRUCTION AND STRENGTH OF TYPICAL FOUNDRY IRON MIXTURES.

The chemical construction and highest strength of all the prominent mixtures now being used in general founding, as obtained by the author for this work to illustrate in a concise and accurate manner true analyses of mixtures actually used by our leading founders, are shown in Tables 29 and 30. The specimens analyzed are taken from the respective tests described in Chapter LX. The determinations were made by the able and careful chemist, Mr. W. A. Barrows, Jr., of Sharpsville, Pa.:

Analyses Nos. 1 and 2 are obtained from "air furnace" iron and those of Nos. 3, 4, 5, 6 and 7 from cupola iron. A peculiarity which will attract the attention of those making a study of the following Table is that of the combined carbon being so high, with low sulphur and the silicon not far from 1.00 per cent. in analyses Nos. 1 and 2. This illustrates the benefit derived from melting iron in an "air furnace," where it is not brought in contact with the fuel to so radically change the character of iron, and clearly demonstrates the superiority of the "air furnace" over the cupola to refine or obtain the best strength possible in cast iron.

The author has not seen any analysis of cupola iron showing the combination of high combined carbon and silicon with the low sulphur shown in analyses Nos. 1 and 2. If any can closely duplicate such a combination of metalloids by cupola iron they should obtain about the same results in strength derived from the air furnace meltings. This may be closely approximated, but the uncertainty of cupola workings, on account of the iron being in contact with fuel and blast, makes it a difficult and a very unreliable method to adopt.

The state of the combined and graphitic carbon is the final resultant of the combined effects of all the other metalloids and chiefly defines what character the physical qualities will assume, as regards the strength, deflection, contraction, and chill of an iron.

TABLE 29.—CHEMICAL ANALYSES OF SPECIALTY MIXTURES IN CAST IRON.*

Arranged according to degrees in strength.

No. of Analysis.	Specialty Mixture.	Sil.	Sulp.	Phos.	Mang.	Graph. Carbon	Comb. Carbon	Total Carbon
1	Gun Metal.	1.19	.055	.408	.420	2.050	1.130	3.180
2	Chill Roll.	.71	.058	.543	.390	1.620	1.380	3.000
3	Car Wheel.	.86	.127	.348	.490	2.550	.920	3 470
4	Heavy Machinery	1.05	.110	.543	.350	2.650	.330	2.980
5	Light Machinery	1.83	.078	.504	.310	2.500	.430	2.930
6	Stove Plate.	2.59	.072	.622	.370	2.950	.350	3.300
7	Sash Weight.	.18	.138	.094	.350	.150	2.940	3.090

*Nos. 1 and 2 are charcoal irons.

Iron of the analysis shown in gun metal can, in castings three inches thick and over, be readily machined and with greater ease than that composing the chill roll mixture. Next in hardness to the roll iron is the car wheel metal, the other specialties following in degrees of softness in the order shown, until sash weight iron is reached, which specialty excels all shown for being a hard metal as such is strictly a "white iron." The following Table is a summary of the best strength obtained from a series of about 100 tests taken with bars one and one-eighth inches in diameter, twelve inches between supports, in obtaining the transverse strength, more fully described in Chapter LX. A column is also given showing the tensile strength of all these specialties.

TABLE 30.—SUMMARY OF TYPICAL AMERICAN FOUNDRY IRON TESTS.

Taken with one square inch area test bars.

Specialties of Mixtures.	Transverse strength per square inch.	Tensile strength per square inch.
Gun Metal	3,686	37,110
Chill Roll	3,044	30,661
Car Wheel	2,819	25,782
Heavy Machinery	2,791	25,799
Light Machinery	2,115	20,655
Stove Plate	1,813	12,582
Sash Weight	1,480	7,044

The Table 30 is no discredit to American foundrymen. It displays to the world typical irons challenging competition in excellence for the various specialties shown.

Ductile cast iron is the term applied to a product now being introduced by the East Chicago Foundry Co., for which a tensile strength of 50,000 to 80,000 pounds per square inch is claimed. The author has endeav-

ored to obtain all particulars connected with its manufacture, but has found the process one of which the manufacturers do not, as yet, care to impart any knowledge. It is claimed the metal can be forged when heated and that there is no difficulty in obtaining sound castings, as is generally the case with strong metals. It is thought it will replace drop forgings in many instances. However, it is an advance for cast iron which still more strongly encourages the author in laboring to do his part in pressing it to the front in order to retain its supremacy as being the world's metal, far excelling all others in combined tonnage for use in the mechanical arts.

CHAPTER XLI.

CONSTRUCTION OF CHEMICAL FORMULAS AND EFFECT OF PHYSICAL ELEMENTS IN CASTING CHILLED WORK.

Chemistry has proved of greater benefit in making mixtures for chilled castings than in any other line. When the progressive founder thinks back to the days when the chill roll, car wheel, and other manufacturers were wholly guided by judgment of fracture in selecting their pig metal to make a mixture, he is not at a loss to comprehend why such bad results in castings were then obtained, accompanied by heavy financial losses.

In making grey iron castings, there is a much greater leeway for a divergency from the best point to be reached as regards the "grade" desired than with chilled work. In many cases where soft work is wanted it may be found very hard and still be passed, or do no injury other than cause extra labor in finishing the castings, etc.; but as a general thing if chilled mixtures diverge much from the best point to be attained, the castings will prove worthless by reason of "chill cracks" or the "chill" not be of the depth or quality of hardness desired. It is true that most chilled work founders would take "chill tests" of their mixture after they had melted their irons. This

would to a great extent be a guide for their next "heat," providing the pig metal to be used was exactly the same. In melting iron in an "air furnace" there is a chance to change its composition from what a "chill test" might prove it, before the metal would be tapped or poured into a mould; but with cupola work such a practice is not admissible. Small cupolas may, in some cases, be used to test pig metal before it is used in regular cupola mixtures, but analyses are generally a cleaner and preferable plan. It is only where analyses cannot be obtained or relied on that testing pig metal in small cupolas, before being used in regular mixture, is a plan which it may, in some cases, be well to adopt.

The above treatment of this subject is not to be taken as decrying the plan of taking "chill tests" of mixture in any or all cases, as such course is advisable under all circumstances, since it enables a founder having experience to form a close estimate of what he has obtained in his castings and assists him to know whether a change in the chemical properties would be advisable for any following heats. Chilled work will always crystallize in planes at right angles to the chilling surface of the iron mould used for chilling the casting. A standard chill which the author has devised for testing the "chill" of iron can be seen in Chapter LXIX.

The elements most constant in testing the chill of an iron are heat and friction. Heat is the best element for testing the durability of such castings as rolls, and friction those like car wheels. It is not to be taken for granted, as held by many, that "white" or chilled iron has no degree of hardness or that the depth of a chill determines the hardness, for this is not true. We may have two castings of exactly the same depth

of a chill or that may be wholly "white iron" and still find difference in the hardness of iron. A good article on testing hardness, etc., appears on page 329.

The success of chilled work is as dependent upon the degree of hardness of the chill as upon its depth. One set of conditions may exact a harder chill than another, and what may prove best in one line of work may be a failure in another; as, for example, the same kind of chill would not answer as well for paper or calender purposes as for steel or iron rolling. Variations in sulphur, manganese and phosphorus are chiefly potential in giving a special character to the hardness of a chill.

For "friction wear," as with car wheel, high sulphur will give better life than high manganese combined with low silicon, to cause chill. For "heat wear," hardness or chill is best obtained by high manganese in preference to sulphur combined with low silicon. Chilled iron is rarely, in any case, a homogeneous mass, and sulphur, more than any other element, retards the union of the molecules to best attain tenacity in the life and wear of iron subjected to heat. While it is true that we find in present practice that hardness is generally obtained by the higher sulphur, as can be seen from many of the analyses shown herein, and others recorded, still wherever manganese can be applied in preference to sulphur, to affect the carbon, in giving hardness to chill rolls, etc., better results in casting and the product may be expected. A chill which is chiefly promoted by manganese will prove more yielding to strains and not so liable to chill-crack from heat as a chill which has been chiefly promoted by sulphur.

Then again, manganese causes a more gradual decline from the white to the grey in chilled castings

than does sulphur. The effects of manganese are often neutralized by the sulphur it expels; hence its power to increase hardness may often be very light or nothing, and thus often call for a large increase in manganese before it can produce any effect.

Combined carbon being the element necessary to create a chill, we are forced to recognize it as a leader to which all other elements must lend their aid in influencing its percentage, which for chilled work may range from .5 to 1.5. The greater the percentage of carbon the higher can it be thrown into a combined state by the influence of the other metalloids, and hence the more carbon the deeper can work be chilled, all the other elements remaining fairly constant.

Referring again to the reason why like depths of chill do not present like degrees of hardness, the reader's attention is called to Prof. Ledebur's division of the carbon into several states, wherein he describes elements, as seen in Table 31, existing in carbon as "hardening and carbide carbon." The Professor treated these properties at great length in a paper read before the Iron and Steel Institute, as found in their Proceedings, No. 2, 1893. There is no question but that such a division of the carbon can allow chemistry to account for some qualities in physical effects which at present are not intelligently explained.

The author could, at this point, give analyses of many different mixtures for chilled work, but owing to the conviction that the presentation of the same would, if anything, only confuse rather than enlighten, we only publish the following, in Tables 31 and 32, which are to be taken in connection with those shown in Chapters XL. and LXIX., pages 320 and 525.

TABLE 31.—ANALYSIS OF TWO ROLLS THAT STOOD WELL.
BY PROF. A. LEDEBUR.

	Roll 1.	Roll 2.
Hardening Carbon	0.58	0.45
Carbide Carbon	2.43	0.46
Graphite and Temper Carbon	0.19	1.93
Total Carbon	3 20	2 84
Silicon	0.83	0 80
Manganese	0.15	0.16
Phosphorus	0.88	0.88
Sulphur	0.10	0.10

TABLE 32.—ANALYSIS OF A REMARKABLY STRONG CAR WHEEL.
BY MR. A. WHITNEY.

Combined Carbon.	Graphite.	Manganese.	Silicon.	Phosphor.	Sulphur.	Copper.
1.247	3.083	0.438	0.734	0.428	0.080	0.029

The manufacture of chill work has grown to such an extent that we find the following castings being produced: Rolls for various purposes, car wheels, crushers for breaking ore, etc., squeezers for making balls of iron, die presses and anvils, armor for inland fortifications, shot and shell, frogs and switches for railroads, axle bearings, grinding and grist machinery, turn-tables and transfer plates, retorts and boiling pans for various chemical purposes, plows, cutting tools and numerous other specialties that might be cited to illustrate the proportions to which the manufacture of chilled castings has extended. Such work forms no small part of founding, and success in obtaining a good product possessing desired qualities has cost more money, worry and labor to the founder than almost all other specialties in castings combined. For this reason a study of the elements involved in chilling castings cannot but prove

of the utmost value to any interested in founding.

In making chilled work, it is essential to understand the various effects which the different metalloids have in controlling the combined carbon, associated with a knowledge of the individual effect of each metalloid in regulating the character of the hardness best calculated to stand the wear of friction or heat, as outlined in the former part of this Chapter.

In a general way it can be said that the percentage of the chemical properties which combine to make chill castings ranges in silicon from 0.50 to 1.10, manganese from 0.55 to 1.50 per cent., phosphorus from 0.20 to 0.70 and in sulphur from .02 to .10, with the total carbon as high as it can be secured.

The quality to be first understood is the depth of the chill and hardness desired in a casting; second, the chilling properties of the iron to be used. To make a comparative test in order to learn of the chilling qualities of an iron by casting chill specimens, it should be remembered that "hot iron". will chill deeper than "dull iron," and that note should be taken of the same, in connection with the other elements of chilling, as outlined in Chapter LVI. It is also to be remembered that manganese will give longer life to the fluidity of metal than sulphur, where preference can be given either, in producing the combined carbon. It is very important in assisting to prevent "cold shuts" or "chill cracks," when pouring a mould, to have the metal run freely, and hence the advantage of manganese over sulphur, as above stated.*

*Information on the thickness of chills, methods for making and pouring "chilled" castings, also making clean and smooth and perfect work, can be found on pages 272 and 276 in "American Foundry Practice," and page 234 in "Moulder's Text-Book."

CHAPTER XLII.

HARDNESS OF CAST IRON AND ELEMENTS IN MELTING AND TESTING.

An opinion prevails among founders and many interested in the use of castings that there is no difference in the hardness of "white" or "chilled" iron. Tests have shown such opinions to be in error and that we can have quite a variation in the hardness of cast iron after it has once become "white" or "chilled." With many lines of work it is almost as important to be assured of the character of the hardness as it is to possess knowledge of any other physical property of the iron, in order that the best service may be secured.

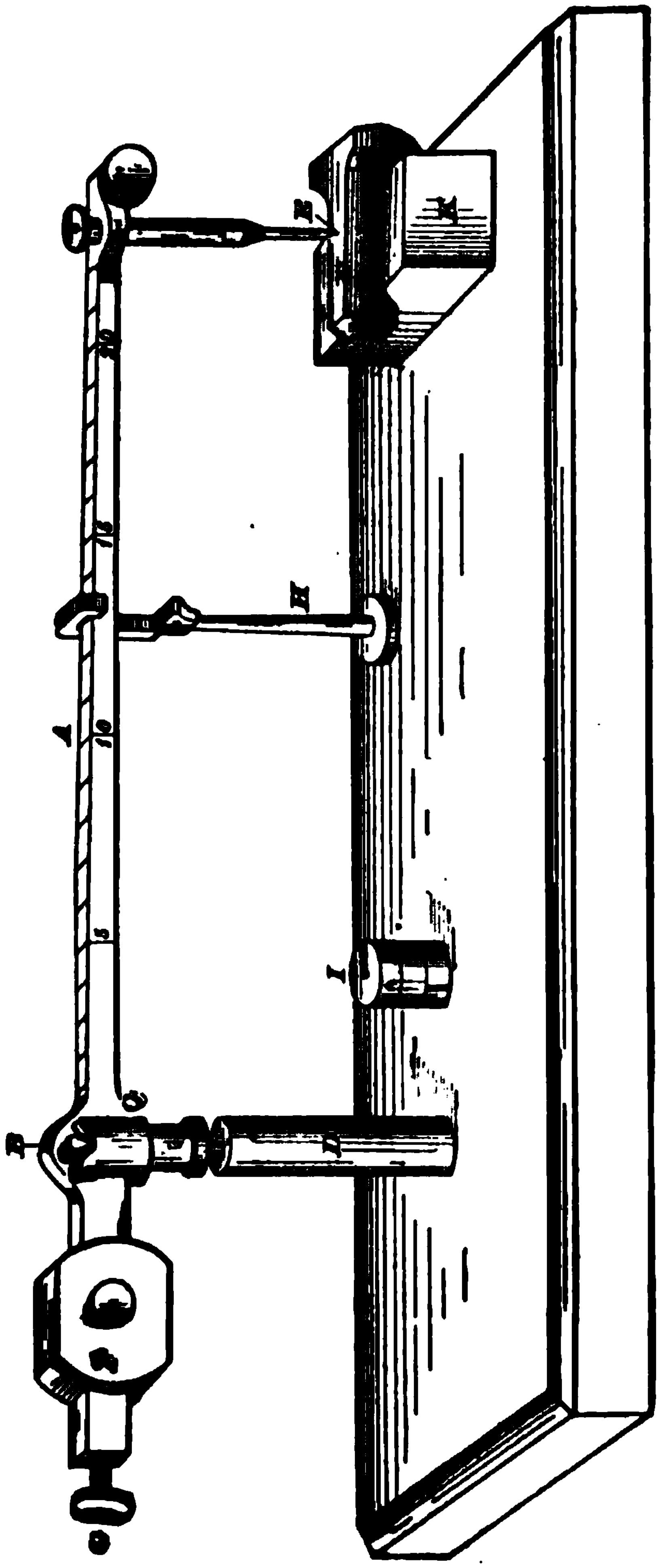
Many plans have been used to ascertain the relative hardness of material. One which was popular for a time is said to have been proposed by Moh, which was classed under three heads: (1) any material which could be scratched by a finger nail; (2) that scratched by a knife blade; (3) that affected by a file. After the above came the weighted diamond point, followed by the punch struck with a given weight. The diamond point device was used by means of weights sliding on a lever, and as the specimen to be tested was moved the weighted diamond would trace a scratch or leave a cut, the character of which recorded the hard-

ness of the material. An apparatus was also used having an obtuse-angled hardened point which would fall from a height upon the specimen to be tested, and according to the size of the indentation made the hardness was defined. A late method is that of testing hardness by means of electricity, in which a current passes through the specimen to be tested and through other standard pieces. The current necessary to produce fusion is observed and compared with that of the normal pieces when they fuse.

The most generally recognized modern device for testing relative degrees in the hardness of metals is that of Professor Thomas Turner, who stands at the head by professional men in advancing knowledge on iron, etc. It affords the author much pleasure to here present a cut of the device, accompanied by a description in the professor's own language:

My first arrangement is as follows, Fig. 64: It consists of a balanced and graduated beam of gun metal A working on steel knife edges B and counterposed by means of a large sliding weight F, the final adjustment being obtained by the screw G. When balanced, it is sensitive to 0.01 gramme at E, though such delicacy is not probably required. The knife edges rest upon planes in the support C, which is capable of rotating on a steel pivot connected with the rod D. The diamond is mounted in a brass tube, having a milled head which is fixed by means of a screw at E. The specimen to be tested, which often takes the form shown, J, is supported by a wooden block K. The weight H is arranged so that each division on the graduated scale shall correspond to a pressure of a gramme at the diamond point. Thus, at division 12, we have a pressure of 12 grammes on the diamond. Three extra weights, I, are used when necessary. They are each of the same weight as H. Hence, with one weight, scale division 10 corresponds to 10 grammes on the diamond, with two weights 10 corresponds to 20 grammes, with three weights to 30 grammes, and with four weights to 40 grammes, the other scale divisions

being read in an exactly similar manner. It will be noticed that the specimen is stationary while the diamond is moved, thus differing from the sclerometer as applied to minerals; the method of supporting the beam and of applying the weight is also different. In ordinary experiments, where considerable weights are applied, the diamond may be moved by the finger, and as the apparatus is very steady in its actions, with a little care this gives very concordant results. For more delicate observations with smaller weights, the diamond may be drawn by means of a horizontal string running over a small pulley. The surface used is prepared roughly in the ordinary way by chipping, filing, etc., and then with a smooth file; it is finished with emery paper, using at last the finest variety, or flour emery, and oil, according to the material.



A. Beam.
B. Knife-edge.
C. Rotating Support.
D. Steel Rod and Pivot.
E. Diamond.
F. Sliding Weight.
G. Adjusting Screw.
H. Sliding Weight.
I. Extra Weights.
J. Test Piece.
K. Wooden Support.

FIG. 64.

It should be finished all one way, so as not to leave small, irregular scratches, and should be as smooth and bright as possible. As a rule, an experienced workman should not take more than half an hour in preparing such a specimen, although occasionally a hard material will take longer. If the surface tested be rough, the results are erroneous, being generally higher than with a good surface. It can, however, be told at once on inspection whether a surface is suitable for the purpose. If any doubt should exist, another smooth face must be prepared and the experiment continued until uniform results are obtained.

The following Table prepared by Professor Turner clearly presents the utility of his device and illustrates the thorough manner in which he completed his work. It is generally thought by founders of the present day that there is no limit to silicon softening iron, but this would be strongly refuted by the following Table and sustain Professor Turner in statements made in other writings to the effect that silicon can harden as well as soften iron:

TABLE 33.—INFLUENCE OF SILICON ON THE HARDNESS AND TENACITY OF CAST IRON.

No.	Silicon per cent.	Tensile Strength.	Hardness.
1.	0.19	10.14 tons.	72
2.	0.45	12.31 "	52
3.	0.96	12.72 "	42
4.	1.96	15.70 "	22
5.	2.51	14.62 "	22
6.	2.96	12.23 "	22
7.	3.92	11.28 "	27
8.	4.75	10.16 "	32
9.	7.37	5.34 "	42
10.	9.80	4.75 "	57

WORKING QUALITIES.

1.—Very hard indeed.
2.—Very hard, though not so hard as No. 1.
3.—Hard, though softer than No. 2.
4.—Good, sound, ordinary, soft-cutting iron, of excellent quality.
5.—Rather harder than No. 4.
6.—Like No. 4.
7.—Like No. 6, but rather harder.
8.—Rather harder than No. 7, though not unusually hard.
9.—Still harder, cutting very like No. 10.
10.—Hard-cutting iron, though still softer than No. 1.

In one sense we have no physical test that has proven more unsatisfactory than that of obtaining the hardness of iron; still for all this we know that differences in degrees of hardness exist in all grades of iron, and in some cases any means which will afford a relative knowledge of the hardness of cast iron will prove of practical value.

The question of whether hard or soft iron will melt the more easily is one often of much importance to the founder. There are but few machinery or jobbing shops that are not almost daily called upon to bring down hard or soft "grades" in the same "heat."

To know what will melt the most easily is necessary to assist in preventing the "grades" getting mixed and thus often making work hard that should be soft, and vice versa.

To show authority for hard or strong grades having a lower fusing point than soft grades, I would refer to the following: "No. 1 iron has a higher melting point than No. 2"—Spretson, page 24. "The degree of fusibility depends on the amount of carbon which it contains," *Strength of Material*, page 31—John Anderson. "Fusing point of grey cast iron, 2.192 degrees; white cast iron, 1.922 degrees, Fahr."—Pouillet, in *American Cyclopedia*, Vol. VII., page 546. "Silicon melts at a point above pig iron; grey pig difficult of fusion; white iron readily fusible,"—*Barker's College Chemistry*, page 265. And Mr. Bloxham in comparing grey and white iron says: "The larger proportion of metallic iron contained in the grey cast iron causes it to require a higher degree of heat before it begins to exhibit signs of fusion, but it is capable of becoming very liquid at a sufficiently high temperature

so as to be easily run into moulds." "White cast iron, on the other hand, is softened at a rather lower temperature, but does not flow well."

If there are two, three, four or five grades of iron to be taken out of a cupola at one heat, the hard or strong iron—if desired to make a good, sound, clean casting, —should generally be charged first, and then again, this is well in order to prevent it from melting and dropping down to contaminate soft iron, as would occur if the latter were the first charged.

CHAPTER XLIII.

AFFINITY OF IRON FOR SULPHUR AND ITS EFFECTS IN STRENGTHENING CAST IRON.

We often have cause to fear evil results from sulphur in fuel and iron, owing to the affinity which iron has for sulphur whenever it is re-melted. The following tests can be repeated by any who may be desirous of studying this question:

TABLE 34.—SULPHUR TEST.

No. of Test.	Quality in Casting.	Micrometer Measurement.	Contraction.	Deflection.	Broke at—in lbs.	Chill.	Strength per sq. inch.
18	Direct bar	1.100	6-32	.090	1385	⅛"	1457
19	Sulph. "	1.089	7-32	.050	1860	all.	1997

TABLE 35.—CHEMICAL ANALYSIS.

No. of Test.		Silicon.	Sulphur.	Manganese.	Phosphorus.
	Iron charged.	.98	.015	.30	.092
18	Direct bar.	.77	.079	.31	.097
19	Sulph. bar.	.86	.175	.37	.097

Test bar No. 18 is one of four which were poured with iron direct from the cupola, with the ladle holding about 100 pounds of metal. After pouring these test bars, about 20 pounds of this metal was then poured into a hand ladle, the bottom lining of which was composed of fire clay mixed with about two and

one-half ounces of pulverized brimstone. The 20 pounds of metal was allowed to stand in the hand ladle about forty seconds, when two test bars were poured, both of which, when broken, agreed very closely in strength. The stronger one of these is recorded as test bar No. 19. All of these test bars are of the round form and cast on end. It will be seen by a comparison of the analysis of these two test bars, Nos. 18 and 19, that the latter absorbed or contains .096 more sulphur than the bar which was poured direct from the cupola, and .160 more than the iron charged. In breaking these bars it will be seen that the high sulphur bar No. 19 stood 540 pounds more than the direct bar No. 18, thereby asserting that sulphur will strengthen iron. But whether or not such an increase in strength in test bars could be beneficial to castings will depend largely upon the internal strains which the addition of sulphur causes in increasing the contraction. This can be seen by Table No. 34, in which the sulphur bar will be seen to have contracted 1-32 inch more than the direct bar. I have conducted a number of experiments in adding sulphur to the molten metal with iron ranging from one per cent. to two per cent. of silicon, and have found it to increase the strength of the test bars. This is to be expected simply from the fact that sulphur increases the combined carbon. With two per cent. in silicon in testing one-and-one-eighth-inch round bars, I have found it only to increase the strength from 150 to 200 pounds, thus showing that the higher the silicon, the less effect the sulphur has in strengthening the iron to the limit of its absorption. Views of the fracture of the above bars, described in Tables 34 and

35, can be seen in Fig. 63, Chapter XXXII., page 275.

Iron most readily absorbs sulphur from the fuel when being re-melted. I have records of its increasing at one re-melt the percentage of sulphur from .030 to .105, with fuel below one per cent. of sulphur, and the iron charged averaging about 1.60 of silicon.

It is no uncommon occurrence for iron to be as high as three to four per cent. in silicon and to contain as high as .200 in sulphur, thereby proving that iron can be high in sulphur, while at the same time it is high in silicon.

While sulphur can give increased strength to iron, to a limit, it is of such character as to greatly decrease resistance to deflection or elasticity of iron. On this account I would say that in such castings as chill rolls and ingot moulds, which have their surface and body subjected to heat, requiring conditions in metal to admit of expansion and contraction, following each other closely, excessive sulphur is to be guarded against, and in light or medium machinery it is injurious, by increasing the contraction and chill or hardness of castings. The former element is injurious in causing internal strains, and the latter in causing castings to be harder than desired.

CHAPTER XLIV.

MIXTURES AND ELEMENTS DESIRABLE FOR ELECTRICAL WORK.

Castings for electrical work were supplied by our foundry for several years to a leading manufacturer. It was with much surprise that we found, when first commencing this work, that no one in the plant using our castings knew what chemical properties were essential to exist in their dynamos, other than that the buyer wanted them soft, as it was found that a hard metal resisted the action of the current and did not form a good magnetic conductor. To give an idea of what properties are essential in castings for electric work, the following analyses of drillings which were taken from a dynamo casting for the author, which had proven to possess good electrical induction or magnetic permeability, is presented:

TABLE 37.—CHEMICAL ANALYSIS OF DYNAMO IRON.

Silicon.	Sulphur.	Phosphorus.	Manganese.	Graph. Carbon.	Comb. Carbon.	Total Carbon.
3.190	.075	.890	.350	2.890	.060	2.950

A study of the above analysis will show the product to be a very soft iron, which in a general sense covers the requirements; and when it is said that all elements should be avoided which favor the formation of combined carbon, the founder has a key to guide him in

making mixtures for castings expected to convey electric currents.

It will be seen that the silicon in the above analysis is as high as 3.190, a point rarely attained in other specialties of casting, but it will be noticed that the sulphur is also well up, so that it greatly neutralizes the softening effect of the silicon. If the sulphur were about .050, the same softness would be obtained with about 2.60 of silicon, so powerful is the effect of a few points in sulphur to promote combined carbon.

In testing a casting to discover its degree of softness by analysis, it is only necessary to first find its percentage of combined carbon, which should not exceed .70 and is best kept down, if possible, to about .30. If an analysis shows the combined carbon to be too high, then determinations should be made of the sulphur and silicon contents of the iron, to learn if either of these elements is at fault, as these properties are the bases in changing the "grade" of iron to control the carbon in taking the graphitic or combined form. The higher the carbon, and the more it is thrown into the graphitic form, the better the iron for electric work.

The effect of high phosphorus is to slightly retard softness, and for this reason it is also best kept as low as is consistent with obtaining any fluidity desired. Phosphorus should not exceed .70, unless some very thin castings are to be made, or there are parts in heavy castings difficult to "run;" then phosphorus may be allowed to approach .90.

Manganese in iron for electric work is also a factor which requires watching, as its tendency is to promote hardness or combined carbon. It is best to not exceed .350, unless the silicon is over 3.00 and the

sulphur under .075, then the managanese might be permitted to go higher. Manganese is somewhat deceptive, as it will permit a casting to arrange its crystals in large grains, giving the iron the appearance of being high in graphite when at the same time the metal will be much harder than if the large grains were all the result of silicon in giving the iron large grains.

By a study of this Chapter it will be observed that the state of the combined carbon is the chief factor in determining the utility of a casting for electrical purposes. We have stated that it is desirable that combined carbon should not exceed .70 in any casting. It is to be remembered that the thickness of a casting and the time it takes the molten metal to solidify have also a great influence in determining what percentage of combined carbon a casting will contain. The more quickly a casting cools the higher will be its percentage in combined carbon. For this reason it will be evident that thin castings would require higher silicon and lower sulphur, also manganese, than thick castings.

With all the above elements to influence the formation of combined carbon, it is evident that it would not be practical to here attempt to prescribe what percentage of sulphur and silicon a mixture should contain. All that can be done is to illustrate the fundamental principles involved, and these, as here stated, taken in connection with the effect re-melting of iron has in increasing or decreasing the chemical properties of a mixture, as outlined in Chapter XXXIX., page 312, will permit any founder making a half study of this Chapter to intelligently formulate a mixture which will work well for any thickness of castings to be used for electrical purposes.

CHAPTER XLV.

LOSS OF IRON BY RE-MELTING AND SLAGGING OUT.

This is revised copy of a paper sent by the author before the Western Foundrymen's Association, April 18, 1894. As the discussion on this paper was of much value, the same is presented with this Chapter.

The percentage of iron lost in re-melting and in the slag is a question often of much importance, in order that such loss may be known and guarded against. The author was led into an investigation of this subject at one time on account of a peculiarity in the formation of slags that occurred for three consecutive "heats." Instead of the slag being of the usual character, it was of a frothy and foamy nature, so as to be fully four times the bulk ordinarily obtained. It was one of those occurrences that come but once or twice in a life-time. The slag when analyzed was found to contain an oxide of iron equivalent to 26.80 per cent. metallic iron. In addition to this there was 1.97 per cent. of very fine shot iron in the sample of slag selected. This, no doubt, was the droppings of melted iron, which elsewhere than at the slag-hole would have found its way to the bottom and constituted part of the liquid metal to be drawn off at each tap. The fine shot iron, I consider, is likely to occur at any heat, the

quantity escaping with the slag being dependent on the pressure of the blast and the size of the slag-hole. At the time of our creating such an extra bulk of slag, we learned that the furnace making our iron had just changed to a new mixture of ores, and this fact rather led me to think something might be wrong with the ores or their working in the blast furnace; for, in re-melting the iron, I never saw such a volume of slag come from all pig iron. As it came out it would foam up in bodies enclosing a gas that would act under it similarly to a foaming yeast. I regret we did not gather and weigh all the slag, for I am inclined to think we did not have any excess in weight over any ordinary heat where the slag runs out and solidifies in a fairly condensed body. But whether it weighed more or not, I do know it occupied fully four times the bulk of what generally comes from such sized heats. If it was not wholly due to the iron, it might be ascribed to an excess of air blowing in through the upper tuyere, E, Fig. 65, page 343, which upon the days in question was about four inches in diameter, and later on was gradually reduced to three inches diameter. Then again, it might have been due to a combination of these two elements. The iron might have had some peculiarity that took kindly to being oxidized to a foaming slag, and the little excess of air at this elevation overcame the balancing point, and thus caused the excessive bulk of slag we received. It might be well to state that the coke and limestone were the same on the days which the slag gave trouble from foaming as before and after that event. The furnace superintendent, Mr. P. C. Reed, seemed inclined to think it might be due to the

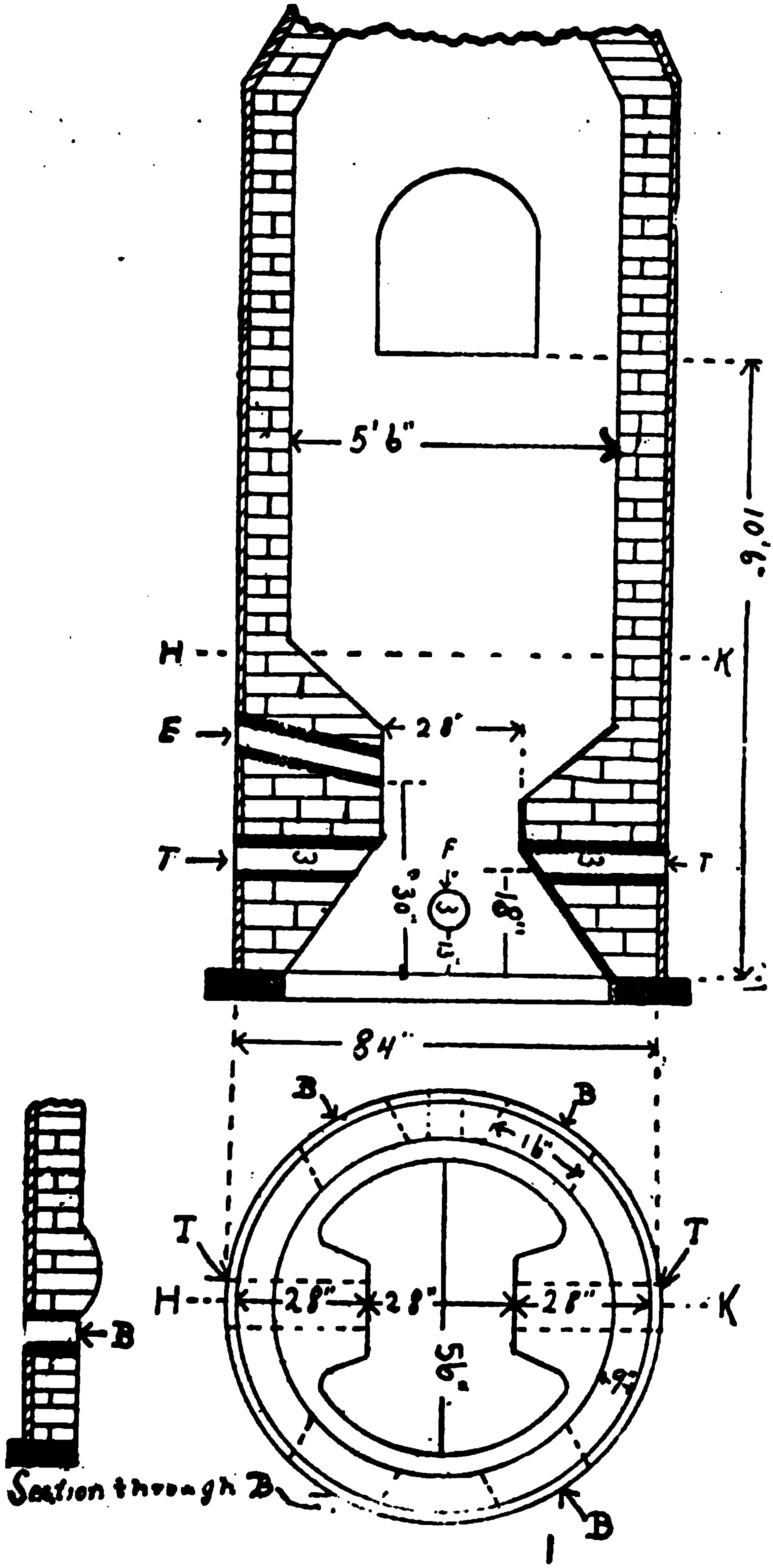


FIG. 65.—WEST'S PROJECTING CENTER TUYERE CUPOLA.

iron. In fact, he admitted that the slag coming from the blast furnace at the time of the change to the new mixture foamed up just about the same as the slag did from the cupola. In this coincidence no doubt lies the key to the whole problem, as when we look to the blast entering our cupola we find all the difference that could exist would be the reduction of the diameter of the upper tuyere E, Fig. 65, from four inches down to three inches. It hardly seems possible that this should account for the large volume of foaming slag we found coming from our cupola, especially as the blast we use is mild in its force and our conditions were the same excepting the size of the tuyere E as explained above before and after this occurrence, as they were at the time of the three "heats" cited as giving trouble with the foaming slag.

Since this occurrence we have given considerable attention to the slag question. Mr. McShiras, the chemist, finds by chemical analysis the following weights of iron to be lost through slags: In a heat of forty tons, March 15, 1894, we had slag coming from the slag-hole weighing 1,700 pounds. The analysis showed this slag to contain 3.34 per cent. of shot iron and oxide of iron equivalent to 17.25 per cent. metallic iron, a loss of 350 pounds of iron in the 1,700 pounds of slag, and to the total weight of iron charged the percentage of loss would be thirty-nine one-hundredths of one per cent.

Another heat of forty tons on March 19, 1894, which we followed up, showed the slag to weigh 1,630 pounds. The analysis of this gave 2.70 per cent. shot iron and an equivalent of 15.69 per cent. of metallic iron, a loss of 300 pounds in 1,630 pounds of slag, and to the

total weight of iron charged the percentage of loss would be thirty-three one-hundredths of one per cent., which, figuring the iron at $12 per ton, would show a loss of $1.58, or a little less than four cents per ton. One factor which it will be profitable to dwell upon before proceeding further with the paper is the reason for the difference of loss in the two forty-ton heats. As our metal is carried away from the cupola by a five-ton ladle, and there are often lulls in getting back with the crane ladle, I have permitted the practice of leaving the slag-hole open all the time, so as to make sure that the slag or metal does not reach the tuyeres. Feeling satisfied we were losing some metal by letting the blast continually blow out of the slag hole, I decided to try in the second heat quoted to plug and tap the slag-hole at intervals, or just a few minutes before tapping out. By doing so we obtained, as shown, a saving of six one-hundredths of one per cent. of the total weight of iron charged, or in other words, we saved 29 cents in the heat of 40 tons at the risk of letting the iron or slag fill up the tuyeres, and hence bung up the cupola. By this method of retarding melting, to save a little iron, we might lose several hundred dollars in castings through bad melting or dull iron.

Where conditions are favorable to tapping a slag-hole at intervals, or just before tapping out the iron, the above figures clearly demonstrate the economy of such practice; and it is one that as a general thing can be safely followed; but in cases where the tapping out and plugging up of a slag-hole would require a man solely to look after it, nothing is to be saved by this practice.

We use limestone for a flux. For every three tons we use 90 pounds, placed on top of every charge. There is no doubt that one or two hundredweight of slag could be added to the totals given above, which could be gathered from the skimming of the ladle and the dropping of the bottoms. Our apprehension as to loss of iron through slag was allayed when we discovered it was less than one-half of one per cent. It is generally conceded by founders at large that loss through re-melting unburnt cast iron ranges all the way from two per cent. up to ten per cent., so we must look elsewhere than to slags for cause to effect the total loss generally found.

The heavy character and condition of our work will not permit a following after heats to find out the exact loss, and we can only get at it by deducting the weight of the castings made from the amount of metal bought during one year, which is not a bad plan, as at the end of each year we then take a careful inventory of all stock. For the year 1893 we found a loss from re-melting of about two and one-half per cent. There are chances, as can readily be seen, of part of this being lost in the way of fine scrap mixed with shop sands and dirt, and also wheeled out with the cirder and tumbling barrel refuse, and hence it would not be right to attribute the two and one-half per cent. all to loss by melting. We can look to oxidation for a great percentage of loss in re-melting iron, and the above figures would lead us to believe that the greater loss was by way of the stack. And I also believe that the greater part of the oxidation, or "burning of the metal," as commonly termed, is done above the tuyeres, as the metal is dribbling from the melting

point through the fuel down past the tuyeres to the bath of metal in the bottom, and also from the surface of the metal above the tuyeres at the melting point, as it momentarily exposes a semi-molten surface to the effect of the blast.

I also think there is another feature of this subject that will bear discussion, and that is this: Will not some clean irons oxidize faster than others? We all know that the more surface we expose to the effects of blast and heat the faster the oxidation. And hence with light scrap iron we must expect the greater loss. But take our case, where one is using all good clean pig iron, we might put the question: Are there not chemical compositions in some pig metals more favorable to oxidation than with others? Then, again, another question that will bear investigation is: What does slag come from? Taking the case of the first forty-ton heat cited above, we find that 1,230 pounds of limestone were used, which, combined with the 350 pounds of iron lost, we might figure as chiefly constituting the 1,700 of the slag found, thus leaving us 120 pounds to account for. To cause thought and further discussion I will ask: What does this 120 pounds chiefly come from, scale of the iron, lining of the cupola, or impurities of the fuel? A study of these questions will be a check to prove that slag has other elements than iron and lime to largely cause its creation as weight. I would here "head off" any who might think to suggest our lining as being the cause of the slag, as that showed no unusual wear or burning out. I cannot but think that a discussion of all the above questions will prove valuable to us all. At least I know that preparing this article has led the writer into several new channels of

thought which will be personally beneficial. There are reasons why one founder should be losing ten per cent. and another only two per cent., in re-melting cast iron, and a thorough ventilation of the subject surely could not but be profitable to all concerned.

We present a sketch of the cupola used in Fig. 65. Each "heat" would then average about 50 tons. We use all pig; no scrap excepting a few "gates," which, for a 50-ton heat would weigh about two tons. Our pig averages about 1.60 per cent. in silicon, and .030 per cent. in sulphur,.35 per cent. manganese, .090 phosphorus, and Connellsville coke for fuel, of which 2,000 pounds was used for the bed and 450 pounds between charges. The pig on bed was 8,000 pounds and between charges 6,000 pounds.

Mr. H. L. Hollis: The main part of the discussion should be taken up in answering some of the questions at the end of the paper. Mr. West has overlooked the ash of all his fuel, I think, in making up his slag. He probably has ten per cent. ash in his coke, which would come very close to accounting for the 120 pounds that are lacking.

Mr. J. K. McKenzie, chemist: This paper does not state what kind of fuel they are using. The ash would amount to anywhere from five per cent. to 12 per cent. Mr. Hollis has taken the average of Connellsville coke. There is liable to be more or less variation on account of the different kinds of fuel. There is another point. In re-melting iron there is a loss of silicon. The silicon is converted into oxide of silicon or silica, and goes into the slag as such. This makes the slag weigh more. In melting a large amount of iron it makes quite a considerable weight

of slag. The average loss of silicon in re-melting iron is two-tenths of one per cent. Another point is that the sulphur in the coke partly goes into the iron and some of it goes into the slag. It is an impurity. Also the manganese goes into the slag as oxide of manganese.

Mr. C. K. Pittman: Would these factors make any considerable difference in the amount of slag?

Mr. McKenzie: They do. Then again the hot or cold working of the cupola would made a great difference. I have seen two per cent. of iron in the slag worked in a hot cupola, and 16 per cent. of iron worked in a cold cupola. The iron goes into the slag as ferrous silicate. I would like to ask if any one knows how much limestone is used? My experience would be about one to 25 for fluxing iron.

Mr. Pittman: Mr. West says 1,230 pounds to 40 tons of metal.

Mr. McKenzie: Six thousand pounds of iron to 90 pounds of stone. This is one to 66. Is that not very little limestone to use for fluxing iron?

Mr. Sweeney: It has been my practice not to use much limestone. Would not the barometrical conditions have something to do with it? One day the atmosphere might be heavy and another day it might be light.

Mr. Pittman: I once heard a furnaceman say that if you would tell him the conditions surrounding the furnace he would tell you whether they would make No. 1, No. 2 or No. 3 iron that day.

Mr. Bowie: I have never taken any notice whether atmospheric conditions would have any effect on cupolas. In running air furnaces I have noticed a

great difference on different days. We had a 20-ton furnace and used to light it about five o'clock in the morning. We used the same iron and the same coal and would have the same men working, and some days the iron would be all melted by eleven o'clock and some days it would not be melted before one o'clock.

Mr. Sweeney: While this discussion is a little wide of the slag question, air furnaces are affected by the way the wind blows, but the cupola is not to the same extent. With air furnaces, when the wind blows in one direction the furnace will be very hot, and when the wind is in another direction the furnace will be very slow. This is the same in open-hearth furnace work and we find the same thing in plate-glass factories.

Mr. Pittman: While this is not properly on the slag question, it bears on it.

Mr. Bowie: Mr. West does not seem to have noted so much the difference in actual weight of the slag as in the bulk of it. It was the bulk of the slag more than the actual weight of the iron or any other material. Perhaps our chemical friends can throw some light on the subject as to what caused it to foam. What was it that made it rise and be light?

Mr. McKenzie: In a general way, as we all know, the foamy appearance of most substances is caused by occluded gases. I have not made any special experiments in this case myself.

Mr. Bowie: The loss is so much less than I have ever been able to obtain and the proportion of limestone is so much less—.31 per cent. less in the heat—and I count myself very lucky when I run down to three per cent. The limestone was one to 65, when I

think in ordinary practice it is one to 50 or one to 30. Perhaps our chemical friends can tell us if we have been using too much limestone. Our average loss of iron is about five per cent., that is running from 15 to 20-ton heats a day.

Mr. Pittman: I think there is such a thing as using too much limestone and too much fuel both.

Mr. Leahy: On our every-day heats we only use limestone about one to 50.

Mr. McKenzie: Do you plug up your cinder-hole or keep it open?

Mr. Stantial: There is a difference; some plug it up and some keep it open. I think Mr. West kept it open some of these days.

Mr. Pittman: It might be well to have the experience of the members as to the amount of limestone used.

Mr. Sweeney: I think the matter of limestone should not be compared as between foundrymen, because the man who melts from 15 to 20 tons of iron in a day would not have the same proportion as the man who melts from 40 to 50. It is that difference that makes so many different statements. With 15 to 20 tons I do not think any flux is necessary. The larger the amount of the heat the greater proportion of flux is used. The best place to get statistics about limestone would be in a Bessemer steel plant where the cupolas are kept running constantly and where the comparisons are to some extent alike as between all steel works.

Mr. Whitcomb: I have had some experience in using limestone and I think what makes the iron foamy is too much blast and too much stone. If when the

iron foams you will stop the blast for a few minutes, you will not have any trouble. A man was once having trouble with his furnace in that way and he came to me for advice. I told him to slack his blast and I did not think he would have any more trouble. He came to me afterwards and said that helped him out all right.

Mr. Stantial: I would not think of using limestone with fifteen to twenty tons. On larger heats we have to use limestone. On large heats running from 45 to 50 tons we use from about one to 25 or one to 30. I have noticed the foaming but have never paid particular attention to it.

Mr. Sweeney: I believe an excess of blast would cause foaming of the slag.

Mr. Stantial: We have been told to-night that this foaming could be laid to occluded gases. I rather think that it could be laid to air that is contained in it rather than the gases. The air that is blown into it might cause the foam. With a heavy blast on you will notice heavy festoons of mineral wool hanging all over your rafters. I think that is only carrying the thing a little farther.

Mr. Vrooman: Which slag would contain the most iron; the frothy or the solid?

Mr. Stantial: I do not think that it would make any difference whether the slag was frothy or solid as regards its contents of iron.

Mr. Pittman: If there was an excess of air, would not that cause oxidation?

Mr. Stantial: The air is not acting so much on the iron as on the slag. It is acting on the slag as it passes out of the slag-hole.

Mr. Leahy: Our heats average from 60 to 75 and sometimes 100 tons, but on the first few charges put into the cupola we do not use any limestone at all.

Mr. Stantial: Do you count your average on the total in the cupola, or only when you use it?

Mr. Leahy: Only when we use it.

Mr. McKenzie: What do you understand the slag to be—a solid slag, or a porous slag, something like pumice stone?

Mr. Stantial: Porous, like pumice stone.

Mr. McKenzie: I would quite agree with you if it had a spongy appearance. I would distinguish between porous and frothy.

Mr. Stantial: You break that slag in pieces and you will find cavities in it as big as your fist.

Mr. McKenzie: That is on account of the air and would have nothing to do with the stone.

Mr. Stantial: I think it is more air than stone.

Mr. Johnston: I have no experience in running cupolas, but I have kept the records of small heats in some foundries. I have known them to use from one to 20 limestone and the weight would figure up, melting from 150 to 175 tons per day, something like one to 25. I would say that we did not have very much scrap, nearly all pig iron.

Mr. Whitcomb: It is hard to tell the exact amount of limestone used. With some stone you would use more than others. There is quite a difference in limestone.

Mr. Pittman: I think Mr. Whitcomb's suggestion that the quality of the limestone is to be taken into consideration is a good one.

Mr. Whitcomb: I should think that one to 35 would

be pretty high. In melting, if you are running a big heat in a small cupola, it is necessary to keep the slag running. I mean in taking it out from the slag-hole, so that you can see the iron come right down close. If the hole is open and the iron running right down, the blast will throw it out.

Mr. Bowie: Mr. West seems to lay a great deal of the blame of the conditions on the iron and thinks that they had a similar trouble at the furnace where the iron was melted. If this iron was high in silicon, with a strong blast, would there not be a large oxidation of silicon in the iron, and increase the bulk of the slag?

Mr. McKenzie: The oxidation of silicon would increase the weight but not necessarily the bulk. The silica would make it more compact and glassy. It would take away that porous appearance. It would not increase the bulk. When you are melting a hot iron, do you lose more silicon than when you are melting a cooler iron?

Mr. Bowie: I rather think you do. We have no chemist and I have no figures.

Mr. Sweeney: In the case that you supposed, with their iron containing a small amount of silicon, you used a strong blast. Mr. West says that he used a mild blast. There is quite a scope for discussion here in the amount of blast to be used.

Mr. Stantial: I would like to ask one question: Have any of the members used fluor-spar and limestone in the cupola, and if so, do they consider one better than the other?

Mr. Whitcomb: I have used them both, but I could not tell that there was much difference. I do not think there is anything better to use than limestone clear.

Mr. Leahy: I have used fluor-spar some. It seems as if one could get a very fine slag by the use of fluor-spar and limestone both together. I have used them frequently in that way and found I got a very fine slag. In fact, I keep the fluor-spar on hand right along, but we do not make a practice of using very much of it except when we run out of limestone.

Mr. Pittman: Do you think there is any advantage in using fluor-spar when you have limestone?

Mr. Vrooman: What objection do you have to it?

Mr. Leahy: The objection I have to fluor-spar is that it contains too much lead. It is pretty hard to get it clean.

Mr. Sargent: I should like to ask of the expense of fluor-spar as compared to limestone.

Mr. Stantial: I have used both of them and I have gone back to limestone as answering the purpose fully as well, with a great saving in the first cost. As regards the comparative cost, I believe limestone can be had for one dollar a ton and fluor-spar from six to seven dollars a ton. Although you can use less fluor-spar than limestone, I never could get it down so cheaply.

CHAPTER XLVI.

UTILITY AND COMPOSITION OF FLUXES.

The advent of chemistry in grading and making mixtures of iron should also effect an advance in fluxing cupolas.

The object of fluxing is to give fluidity to the non-metallic residuum of the iron and the ash of the fuel to carry it out of the cupola or furnace in the form of slag, so as to prevent "bunging up," give clean iron and assist in attaining desired results in "grades" or mixtures of iron. When a non-fluxed cupola over-reaches its clean melting capacity, the speed and production of good hot iron becomes rapidly diminished and melting soon ceases. The difference which a good system of fluxing can cause in extending the melting capacity of a cupola and making clean work, both in the manipulation of the cupola and production of good castings, is surprising. All fluxes should be as free from earthy matter as possible, since this retards their fusion. High silicas and sulphur are likewise objectionable. The chemical element most essential in a flux to aid the creation of slag is carbonate of lime. This is found in various forms, as in marble, spalls, oyster and clam shells, limestone, calcite, chalk, dolomite, calc-spar, fluor-spar and felspar. There are certain chemical properties which can exist in fluxes to assist in obtaining desired results, just as there are

certain chemical elements necessary in iron to obtain the grade required.

We have patent fluxes which are often placed upon the market by parties claiming for the same exceptionable virtues in the line of " improving the iron," saving the wear of the lining, and loss in iron. In some ways this may be true, but more frequently the claims would soon be refuted were foundrymen only better posted on the chemical action of their respective fluxes. I do not wish to be understood as denying that some of these patent compounds may make excellent fluxes in certain lines, but the point lost sight of is the claim made of " improving the iron." We might ask in what manner the iron is improved, when we consider that it is only the so-called impurities of iron—silicon, sulphur, phosphorus, manganese, etc., that make iron of any commercial value, since strictly "pure iron" could never be used; and as it is according to the varying percentages of these impurities that the different grades of iron are obtained, it will be seen that the term " improving the iron " is a meaningless phrase, where one compound or flux is intended to be used for all kinds of mixtures, as is often advocated by flux patentees. Any close student of this subject cannot but readily perceive that the effects which any chemical properties of a flux may have in the elimination of impurities so as to " improve the iron," simply means getting nearer to a " pure iron," and this might deteriorate instead of " improve the iron," for the class of work desired. It depends upon what metalloid is eliminated or increased. If the mixture has too much sulphur, phosphorus or manganese, and the flux has an

affinity for either of these elements or all of them, then we could say the iron was improved; but if, on the contrary, the iron required more of either of these elements, then the action of the flux would only injure the iron.

What is necessary to find out, if possible, is: what special effect the chemical compounds of any flux may have in eliminating or increasing the silicon, sulphur, phosphorus, or manganese, etc., in melting iron. These understood, we are in a position to intelligently apply a flux that will really improve an iron for the class of work desired. It might happen that we desired to decrease the percentage of silicon in our mixtures, and we might also find that our mixture was too low in phosphorus, requiring an increase of that element; and so we might cite sulphur and manganese. It will be evident that it is often as essential to understand the chemical properties of our fluxes as it is the iron and fuel and their affinity for each other, in order to work intelligently in making mixtures to obtain the character of iron desired in our castings.

There is always more or less dirt or residue created from the ash of the fuel, scale and sand of the iron and its silicon, which goes to form a slag that can soon "bung up" a cupola. It is rarely that a cupola (without it has exceptionally clean pig and scrap) can be made to run over three hours, without being "slagged out."

The amount of flux to be used is dependent upon the character of the iron and fuel used, the weight of the heat and the character of flux. In the case of limestone, the richer it is in lime, the less stone is required. The weight of limestone necessary to make a fluid slag generally ranges from 40 to 80 pounds per ton of iron. Where all "gates" are "milled" or

"tumbled," as is often done in light work shops, and "sandless pigs" are used (see pages 116 and 290); also a good class of fuel and iron is used, so as to leave a low percentage of residue, it may be that 20 to 30 pounds of good limestone will be all sufficient to make a fluid slag. It is often necessary to experiment with a flux in order to determine what percentage is best to be used. The manner of charging limestone or any flux is generally that of placing it on top of the iron, although it is often charged on the fuel and then again mixed in with the iron or fuel. The plan of placing it on the iron recommends itself above others, as by so doing it leaves the fuel more compact, thus resisting its disintegration when it arrives at the "bed" to replenish the burned out fuel.

The economy of fluxing does not lie in the saving of a flux; sufficient should be used to make a fluid slag. Where a cupola does not slag freely, much iron is often lost by reason of its being carried off with the slag, and the speed of melting is greatly retarded so as to involve loss, both in time and work. For percentages of iron lost in "slagging out," see page 344.

Magnesia largely serves the same end as lime, but less of it is required, viz.: about two of the former where three of the latter would be sufficient. Dolomite contains more magnesia than any other class of limestone, and is often called "magnesia limestone," and generally contains about 55 per cent. of calcium carbonate and 40 per cent. of magnesium carbonate, with the rest largely in silica, oxide of iron and aluminum. Dolomite is now being used in the making of high silicon and other irons, but it is said to not be as effective in lowering sulphur in iron as limestone, where sulphur is troublesome.

The fusing points of the different elements composing a flux are often as important to be understood as their influence in effecting chemical changes in the iron. Some fluxes will require a higher temperature to fuse them than others, and the nearer a flux can be obtained requiring the same temperature to fuse it as to melt the iron to the fluidity desired, the better the results. Where "hot iron" is desired and an increase of fuel is necessary to obtain it, better economy and cleaner cupola work will be obtained by using a flux having a high, rather than a low melting point. This is due to the fact that if a flux should melt much before the iron, it has not the initial heat or fluidity imparted to it that the iron will have, and hence when once settled in a liquid state in the hearth of a cupola, its fluidity can only be increased at the expense of heat extracted from the metal as it drops to the bottom of the cupola; and if the slag is allowed to remain in the cupola or not drawn out as often as it is created, the incoming cold blast will rapidly decrease its fluidity for making a thick slag or "bung up" cupola. As a general thing, it requires a higher heat to fuse a flux than to melt the iron. The slag produced requires a heat of from 2,000 degrees F. to 3,000 degrees F., to fuse it.

In the above hypothesis the founder is shown why, in the use of fluxes, he may at times increase his fuel in an effort to obtain "hot iron," and not obtain the fluidity expected, and it also shows that it is not the physical properties of a flux, but the chemical, that should guide us in selecting high or low fusing fluxes. Some think, for instance, that a soft, friable limestone will fuse more easily than that of a hard char-

acter. The above reasons would show that this is not what would guide us, and that a flux may be very soft in its physical character and still have a high fusing point. There is, however, this to be said about hard fluxes of the limestone character, viz.: that all such fluxes should be broken to about egg size, as this will give a greater area to be exposed to the chemical action of the fusing elements in order to best affiliate in fluid state with the debris of the iron and fuel to create slag.

The more silica a flux contains the greater fuel or higher temperature required to fuse it, and the less its value as a flux, for the reason that more lime is required to reduce the silica to a slag. This is also displayed in making iron, as the more silicious the ore the more lime generally required to flux it. It has been known to require more lime than there was ore charged in order to flux the high silica which the ore contained. Silica in the creation of slag is not only derived from the fuel and ore, but also from the scale and sand on the pig metal or iron charged, as well as from the oxidation of the silicon during a "heat." It is to be remembered that the more lime that flux contains, the greater it serves the end of creating slag to affiliate with the earthy matter and debris formed in a furnace or cupola, and, also, the more silica or lime there is in a furnace or cupola the more fuel required to smelt or melt the iron. Alumina is also pronounced in its effects upon the decrease or increase of the fluidity of slag. As a general thing, the more alumina the higher temperature required to reduce the flux in order to make a good liquid slag.

The following analyses, Table 38, are of fluxes which the author has used within the last few years at our

foundry and will serve to illustrate physical as well as chemical properties, and will also show that a flux, which may work well in a blast furnace, can often be well utilized for cupola practice:

TABLE 38.

	No. 1.	No. 2.	No. 3.
Silica	3.00	1.98	.54
Iron Oxide	.92	.60	.12
Alumina	1.25	.90	.36
Phosphorus	.020	.037	....
Sulphur	.020	....	....
Carbonate of Lime	92.10	82.85	98.78
Carbonate of Magnesia	1.26	13.04	....
Lime Oxide	51.57	46.41	55.32
Magnesium Oxide	1.63	17.23	....

All of the above three fluxes were used on different occasions in melting all pig iron in heats ranging from 40 to 70 tons. They all proved to work well and give a good fluid slag. It will be noticed that Nos. 2 and 3 have no sulphur. For many classes of work this would cause their preference over No. 1, as sulphur in limestone is similar to that in fuel; it largely goes into the iron to raise its sulphur contents. For cupola work, preference, as far as labor is concerned, would be given to Nos. 2 and 3, owing to these being more friable than No. 1, but for price per ton the furnace limestone, No. 1, of course, costs much less.

The physical character of No. 1 is very hard and of a dark color, and is a grade of limestone mainly used for blast furnaces. It is obtained near New Castle,

Pa. No. 2 is of a much softer quality than No. 1 and also more white and clear in its color. It is known as "Kelley Island limestone," and is mined at Marblehead and Lakeside, Ohio. No. 3 is softer and purer in color than either Nos. 1 or 2 and has something of a checked marble cast. It is obtained from the Benson mines, N. Y., and instead of being called limestone, as are the first two shown, it is defined as calcite. All of the above fluxes come to the founder just as they are mined, being in no wise burned or causticised. While this is a treatment necessary to some grades of limestone, it is claimed it will benefit almost any flux of a rock character. When this is done with limestone it gives us "quicklime," a form that requires less weight when charged than limestone. The action of burning or roasting causes the limestone to become friable, so as to largely eliminate its carbonic acid and other volatile matter, and to generally make a limestone less refractory or more easy of fusion. While such treatment of limestone would naturally be expected as being beneficial, it has not really proven so in all cases. Where the fuel necessary to roast it is taken into consideration with that which may be saved in reducing it to a slag in the smelting of iron, there is considerable difference of opinion in regard to the question of economy for furnace practice; nevertheless, the author is of the opinion that for cupola work such treatment of rock fluxes would prove advantageous in most cases.

Matter to be read in connection with this is found on pages 88, 90 and 351, and any desiring information on tapping slag and the placing of slag holes, etc., in cupolas are referred to page 310, "Moulder's Text-Book."

CHAPTER XLVII.

ALUMINUM ALLOYS IN FOUNDING.

Aluminum was discovered, it is claimed, by Frederick Wohler, a German professor, in 1827; but to St. Clair Deville, a Frenchman, belongs the honor of being the founder of the aluminum industry. The first article made of this metal, it is said, was in compliment to Louis Napoleon, the benefactor of Deville, and was a baby rattle for the infant Prince Imperial. About ten years ago it was thought that aluminum would revolutionize all metallurgy, but usage and practical tests have more closely defined its sphere. We find that to-day its adoption is chiefly limited to the manufacture of fancy commercial wares, also alloys of brass and bronze, the former being extended to an industry employing a large number of wage earners.

In the first days of the aluminum industry great difficulty was experienced in obtaining perfect castings with aluminum alloys. It was seldom that a sound casting could be obtained. The Cowles Electric Smelting and Aluminum Co., of Lockport, N. Y., one of the first to manufacture aluminum alloys, etc., engaged the author, in the year 1886, to go to Lockport for a short time. The author's experience in this foundry resulted in finding aluminum, as an alloy, very wild in its actions, and that the greatest difficulty might always be expected with it in obtaining strictly

aluminum bronze castings. I have seen a pot of aluminum bronze kept for twelve hours in a furnace before tests had proven it to be the grade of metal desired, and the chances were that, had it proven all right, if a second test had been taken a few moments later it would have shown that a great change had taken place in the metal. The author succeeded in obtaining sound castings from some very complex patterns, but he was not able to make any formula or directions for a mixture which would insure like desired results every melting, as far as physical tests were concerned. It must be remembered that at this time pure aluminum was not obtained for commercial purposes, as it is at the present day. Then it was only obtainable by being alloyed with iron or copper containing from about 5 to 20 per cent. of aluminum. To obtain 5 to 20 per cent. of aluminum in any alloy of copper or iron, 80 to 95 per cent. of these latter elements had to be melted in mixture with what was in the pot in order to have a chance of securing the grade wanted. Since the advent of the Pittsburgh Reduction Co., about the year 1890, aluminum is obtainable for commercial purposes in a free state, without being alloyed with any other metal. This has proved more satisfactory in enabling a formula to be utilized to the end of securing like results at all times, but has not removed the difficulty of obtaining perfect castings of aluminum bronze alloys.

The author has tried aluminum in mixture with cast iron. In some cases it would slightly improve the strength, and again it would weaken the iron. The influence of aluminum is similar to that of silicon. Where the combined carbon is high, it will lower it so

as to make the iron of a softer nature. Where the graphite is highest, it will close the grain and give the iron a leaden color and generally decrease its strength; whereas the reverse will generally be true if the combined carbon has overreached that point which would afford the iron the greatest strength. On a whole, aluminum, as far as strength is concerned, is only of value in use with very hard grades of iron, or those exceeding 1.35 in combined carbon. The percentage of aluminum which I used would range from one-quarter of one per cent. to 1¼ per cent. The aluminum was placed in the bottom of the ladle and the molten metal poured over it. I found this plan better than throwing it into the molten metal after the ladle had been filled. In both cases the metal would always be stirred with a rod to assist in mixing the metals. Aluminum will increase the fluidity of molten metal, but to obtain the best results in this line it must be used with care and judgment. To secure the greatest fluidity by means of aluminum depends upon the percentages of the elements which compose the iron designed to make it soft or hard. The harder the iron the more aluminum can be used to obtain the greatest degree of fluidity. With soft grades aluminum can make the metal sluggish, with excessive dross on its surface, just as can be the case by having too much silicon in a mixture.

While the way in which aluminum will generally work in affecting the different percentages of carbon in iron are above outlined, still, on the whole, it is very erratic and will often act contrary to expectations. One peculiarity about aluminum alloyed with iron is displayed where two ladles are used to pour a mould,

often showing a "cold shut" or bad union of iron at the point where the streams of metal from the respective ladles meet each other. Aluminum is also alloyed with silver, nickel, tungsten, manganese and silicon, as well as copper, iron and steel.

Pure aluminum is the lightest of all known metals, except magnesium. Its specific gravity is from 2.6 to 2.7 and it melts at about 1500 degrees F. It is white in color, of a soft nature, possessing a strength of about one-third that of wrought iron. While pure aluminum melts at 1500 degrees F., still its reduction in the blast furnace from any ore is such as not to alloy with the iron to any extent. Why the iron will not take up aluminum to any degree in the process of reducing ores is a question still unanswered. It is a test that shows that iron possesses but little affinity for aluminum, so far as proving of any practical value to iron founding is concerned. In all the author's experience with aluminum in cast iron he cannot say that he ever found it to accomplish anything which could not be obtained by means of silicon, which is much cheaper than aluminum.

PART IV.

CHAPTER XLVIII.

INTRODUCTION TO TESTING THE PHYSICAL QUALITIES OF IRON.

In a paper submitted to the Iron and Steel Institute, at Birmingham, England, August, 1895, the author made the following statement:

> For the past four years the writer has been studying the causes of the erratic results observed in testing the physical properties of cast iron, with the object of overcoming them, so far as possible. All the systems adopted in the past are founded upon incorrect principles and are not practically adapted to afford any investigator desirous of obtaining a true knowledge of the physical properties of cast iron any assurance that the tests he may record to-day in defining physical phenomena will not be contradicted to-morrow by himself or someone else.

The above statements will be found to be substantiated in the following Chapters, and no labor has been spared by the author to disclose the qualities causing erratic physical conditions or phenomena.

In order to give a complete treatise on the subject of testing in this part of the work, the author found it necessary to obtain tests and analyses from outside sources. For valuable services rendered in these lines, the author desires to here express his appreciation and thanks to the following gentlemen and firms: Prof. C. H. Benjamin, the Walker Manufacturing Co. and Warner & Swasey, all of Cleveland; E. Duque

Estrada, J. B. Nau, Lewis Foundry and Machine Co., McConway & Torley, all of Pittsburgh; Bissell & Co. and Taylor, Wilson & Co., both of Allegheny, Pa.; Riehle Brothers, A. Whitney & Sons, E. E. Brown & Co., W. E. Webster, David Townsend and David J. Matlack, all of Philadelphia; Builders' Iron Foundry, Providence, R. I.; Lloyd-Booth Co., of Youngstown, O.; Shenango Machine Co. and Graff Stove Co., both of Sharon, Pa.; O. T. Stantial, Chicago, and Chas. A. Bauer, Springfield, O.

Chapter XLIX. in this part of the work presents details for a very small, cheaply constructed cupola and crucible furnace combined, applicable for college, experimental, or foundry work. The Chapter also illustrates the difference to be expected between iron melted in a cupola incased with fuel, and iron melted in a crucible. It also gives all details necessary in operating the same.

Chapter L. describes how to tell the different "grades" which molten iron will insure when solidified, by characteristic qualities which will be displayed when the metal is in a liquid state. It also presents a plan for the rapid determination of a "grade," before iron is poured into a mould, or is still in a "hot" liquid state.

Chapter LI. shows the effects which "hot" and "dull" iron, or degrees in the temperature of molten metal, possess in changing the physical character of iron and the depth of a "chill."

Chapter LII. treats of the specific gravity or density of the upper or lower end of vertical poured or other castings. It also gives reasons why we have cause to expect little or no difference to exist in the density of

the two ends of long, vertical cast bodies, unless they are affected by ill-shrinkage or the chilling effects of a sand or iron mould.

Chapter LIII. treats of the expansion of iron at the moment of solidification. It also illustrates the physical effects which such expansion may have in affecting the shrinkage and solidification of "grades" in iron.

Chapter LIV. defines two elements in iron cooling from a molten to a cold, solidified state, which at the present time is correctly defined by very few writers, and clearly illustrates why the word "shrinkage" and "contraction" apply to two different qualities in cast iron. The Chapter also refers to rules involved in the contraction of iron, in relation to making patterns.

Chapter LV. treats of stretching cast iron, and explains why many engineers, designers, draftsmen, patternmakers and moulders have in the past been at a loss to understand why some castings came out larger than their pattern, although the moulder had done his part properly. It shows how without a possession of this knowledge serious loss may be incurred in some cases.

Chapter LVI. illustrates the principles involved in chilling castings and the effect which several conditions can have in determining different depths of a "chill" in castings, although the same grade of iron may be used.

Chapter LVII. displays for comparison the utility of transverse, tensile, crushing and impact tests.

Chapter LVIII. shows reasons for the wide, erratic difference so generally found in records, when making comparisons between tensile and transverse tests in the past — a condition of things which will continue to be experienced by any making tests with bars cast flat.

Chapter LIX. gives experiments proving that elements which affect the strength of an iron will also affect its contraction. It shows that such qualities are not to be ignored in making small castings or in the adoption of any form of a test bar which might come up for consideration as suitable for testing the strength, contraction or any other physical qualities of cast iron.

Chapter LX. institutes a comparison of strength in the different specialties of mixtures used in founding. It clearly defines the quality of strength which can be rightly expected from special mixtures, and also demonstrates very forcibly the utility of a 1⅛-inch round bar as one standard for making universal test comparisons of cast iron.

Chapter LXI. illustrates the necessity for computing strength records according to strength per square inch, wherever it is desired to be most truly guided by any transverse or tensile breaking loads of test bars, in making comparison of mixtures or the strength of iron.

Chapter LXII. shows the necessity for using micrometer rules in obtaining the total area or size of a round or square test bar where confidence is desired that the best is being done to reduce erratic results to a minimum.

Chapter LXIII. sets forth methods which should be followed in using testing machines.

Chapter LXIV. illustrates the advantages which the round form of test bar has over the square one, in truly defining the natural qualities of an iron. It shows that the square form of a bar is one that should be discouraged and abandoned by all who desire to obtain the most uniform grain in a test specimen, and best relieve it from internal strains.

Chapter LXV. describes a very important discovery which the author has made, showing how bars cast flat are much stronger on one side than on another. It proves how this uneven texture in a bar will cause erratic and unreliable tensile tests. It also demonstrates the great necessity of care being exercised by any tester in always being sure the same side of such bars is placed down when testing for transverse strength, whenever it is expected to get within 200 to 600 pounds of the metal's true strength. In reality, this Chapter does away with the system of casting flat and proves conclusively that only errors may be expected by following such a method.

Chapter LXVI. discusses the necessity and benefit to be gained by blast furnacemen adopting a standard system of physical tests and presents a complete method for working the same, with all details plainly illustrated to enable any to put the system into practice, should they desire to do so.

Chapter LXVII. illustrates appliances and describes a plan for casting round test bars on end with or without fluidity strips attached to the bar. The former method was tested by the Testing Committee of the Western Foundrymen's Association, having the whirl gate attachment, which gave perfect solid bars.

Chapter LXVIII. describes methods which should be adopted and guarded in the moulding and pouring of test bars.

Chapter LXIX. discusses the benefit to be derived by the metallurgical world adopting some one system of physical tests for cast iron, and the necessity for the same. It displays three sizes, 1⅛, 1⅝ and $1\frac{15}{16}$-inch round bars, as suitable for standards to best meet the

different requirements of the various grades of mixtures in founding.

Chapter LXX. presents one hundred items culled from this work to give the conclusions of experiences, studies and results of a large practice, in a concise manner, of making, mixing, melting and testing, all of which are of value to be studied and remembered by any interested in cast iron.

CHAPTER XLIX.

METHODS FOR MELTING CAST IRON TO TEST ITS PHYSICAL QUALITIES.

Owing to the impracticability of judging pig metal by its fracture, the author has thought a Chapter on methods for melting small quantities to test its physical qualities would, in many cases, prove of value, especially where the foundry was not in the position to utilize chemistry.

There are three methods by which iron can be melted for testing its physical properties. One is to take the regular "heats" mixture, another to have a very small cupola expressly for melting light "heats," weighing from 50 to 500 pounds, and the third by means of a furnace and crucible similar to the principle used for melting brass, etc. By using metal from the first, we can at any period of a heat tell the physical properties of any mixture poured at that time. By using the small cupola we can, by proportioning a mixture in light charges, obtain a fair approximate knowledge of the product to result from a like mixture in regular "heats," and also where there are several brands or grades of pig metal, each can be tested separately, to ascertain its physical properties, thus enabling one to detect any brands that might be deceptive in appearance and thereby contaminate and

prevent physical results being obtained from any desired mixture. By melting in the crucible, we can closely tell the physical properties in respect to what the chemical elements would define it in the original state, when not affected by the sulphur, etc., in fuel, but not what it would be when re-melted. Why this is so involves elements most essential for the founder to understand and is further treated in Chapter XXXIX.

Melting a mixture in a crucible, with the expectation of obtaining tests to denote what the physical qualities of a regular cupola mixture would be, is impracticable. These can only be told with fairness by taking tests from the regular "heat." Tests from a small cupola will fairly approach such as an approximation. Both the small cupola and crucible furnace can be said to be of best value only for testing single grades of pig or iron not in mixture; and as both can often be well used to obtain such knowledge of iron in its original state or before being re-melted, I have studied to the point of combining the two, and as a result present the following original device or small cupola, as seen in Fig. 66, page 378. This cupola can be erected in any out-of-the-way place, or alongside a regular "heat" cupola, so that the flue A can be attached to head off the sparks, etc., when used as a cupola, without risk of setting anything on fire, should there be any danger from this; if not, then the cover B could be dispensed with and the flame, etc., permitted to pass out at the top. B is a cover made out of cast iron, having prickers on the under side for the purpose of holding a daubing of clay to prevent the heat of the furnace burning the cover. The handle D is for convenience in lifting on and off the cover when desiring to change or take

out a crucible. The staging H as shown is placed any height to suit the operator. The cupola has four tuyeres, two inches in diameter. In charging to run a "heat," have the coke ten inches above the tuyeres; if coal, seven inches above the tuyeres. The fuel should not be much larger than double egg size, and the bed well burned up before the first iron is charged. On the bed, place fifty to one hundred pounds of iron, which, if pig iron, should be broken in lengths of from five to eight inches. If the pigs were too strong to break by sledging, etc., one-inch holes could be drilled and a punch used to fracture. Should more than 100 pounds need to be melted, charge on ten pounds of coke or coal and on this one hundred pounds of iron, and so continue as long as the cupola works all right. With a

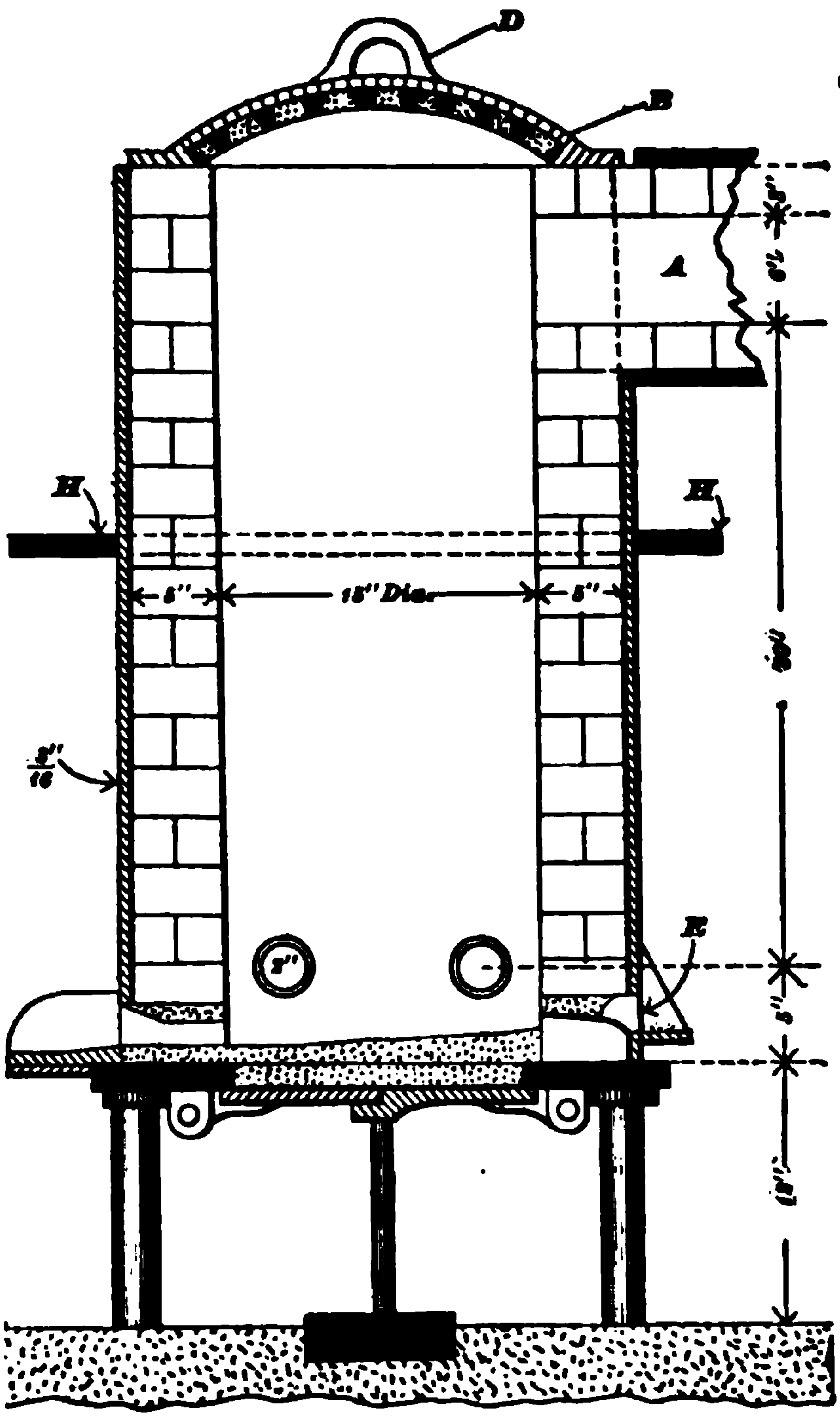


FIG. 66.—WEST'S COMBINED CUPOLA AND CRUCIBLE FURNACE.

slag-hole as at E, Fig. 66, and the use of flux, a "heat" can be prolonged to run several hours. If lime were used for a flux, about four pounds to every one hundred of iron charged should cause the slag to run freely. We are only entering into these details in order to illustrate the fact that the cupolas can be used for heavier "heats" than test bars would necessitate.*

In melting with a crucible in the cupola, Fig. 66, use a size like No. 18 Dixon's brass. In preparing the cupola for melting with crucibles, put in a sand bottom within two inches of the level of the tuyeres. Have a bed of coke, when well burnt up, ten inches high, and on this set the crucible charged with its burden of iron to be melted. Fill all around between the crucible and the cupola lining with small coke, level with the top of pot. Cover the pot over with a clay cover, which can be formed in a core box and rodded the same as one would a dry sand core to prevent its cracking, or the bottom of an old crucible can be used. The smaller the iron is broken the more quickly it will melt, and hence the easier will it be on the pot and more economical in fuel. After the pot is covered, the cover D is placed on to close the furnace. The blast is now put on the same as if iron were being melted direct in a cupola. The pressure should, for crucible work, range from two to three ounces; for cupola work, four to eight ounces can be used, and such

* Should any desire plans, with complete specifications, for constructing small, permanent cupolas, ranging from twelve inches to eighteen inches diameter, strictly for melting light "heats" without crucible arrangements, we would refer them to "Moulder's Text-Book," page 265, and in the same work, page 248, will be found a cheap temporary arrangement for melting from fifty to one hundred pounds of iron.

blast can often be supplied from a blacksmith's forge fan. Should it be desirable to run steadily all day for crucible work, the breast should be dug out about twice during the "heat," and the ash and dross pulled out, so as to leave room for clean fuel. In making the breast for crucible work, have it formed of a sand that will not bake or cake hard and larger than shown. This will permit its being dug out readily.

Should it not be desired to use the device as a combination furnace and cupola, but strictly for crucible work, we would advise sinking the same in a pit, and instead of using the regular cupola drop bottom, which goes with this device, have the bottom consist of a regular grate, with an ash pit six inches deep, the diameter of the grate. Have the ash pit closed air-tight, and instead of admitting the blast into the body of the furnace, as is done with the cupola here shown, let it pass into the ash pit and enter the furnace through the grates. By having a pit three feet by five feet and three feet deep the combination cupola and furnace could be lowered to bring the staging line H level with the floor. This would make it more convenient for charging, or lifting a crucible in or out, and by having a handy step-ladder, ready access can be had to the pit for "tapping out" or cleaning the "dump." For raising a pot of metal up to the floor, employ a pair of tongs similar to those used for lifting a crucible out. The flue A should be lined with fire brick or clay for any distance the outer shell could be heated red hot were it not lined. This flue should be well bound with stays to prevent the heat cracking it open.

As very few founders have had opportunity for experience in crucible work, we will detail some points

necessary to be followed. As melting progresses, the fuel around the sides of the pot will settle down. This must be replenished so as to keep the fuel about on the level with the top of the pot. To have it higher at the first would be an advantage. Judgment should be used to not fill in fuel when the pot is about ready to be pulled out, as this will tend to cool the metal and prevent the free use of the tongs in grasping the pot to remove it from the furnace. A pot will settle more or less in the fuel and it may be necessary to lift it up several times so that the fuel from around the sides can settle down to raise the pot, after which the sides, of course, would require fresh fuel. In charging the iron, the pot may not hold all that is desired at the first filling. In such case, additional iron can be charged as fast as the solid melts down. The crucible will average about forty heats, if handled carefully. The least moisture in a pot would cause it to crack in the fire. It must be thoroughly dry before being used for a "heat." A good practice is to place a crucible in an oven for several days before using it. While it is essential to have the moisture all out of the pot, it is also well to never permit it to cool off suddenly. If after a heat the pot is set back in the fire to cool down with it, its life will be prolonged. Iron melted in a crucible will be found to possess a quiet appearance, and it is generally not so hot as coming from a cupola. In operating either the cupola or the crucible, only the best of fuel should be used, and all work should be intelligently manipulated.

CHAPTER L.

JUDGING OF AND TESTING MOLTEN IRON.

In testing iron we have two properties, chemical and physical, to which we might add the phenomenon of fusion. An old, experienced eye can often fairly tell what a casting will be physically, by judging the appearance of the metal when at rest in a ladle.

In many cases the ability to judge liquid metal will often prove of value, for while we seldom have means for changing its character when fluid, we can often refrain from pouring work when our judgment asserts that a metal was radically wrong. There is this much that can be said of re-melted fluid iron: It will rarely, if ever, deceive an expert, as can the judging of iron in the pig before being melted. We can rest assured that if it looks radically soft in a liquid state, it will not prove hard in a solid one, and vice versa.

The ordinary moulder can, with a short experience, tell the degree of fluidity, or whether the iron is "hot" or "dull." Why he should be better able to do this than judge of its physical qualities when molten, is mainly due to present practice not often affording means to change or correct a metal that might not look right. The quality of the temperature before

being poured he can often greatly control, and hence the advantage of practice in this factor causes study to train the eye, which very soon becomes expert in deciding the best moment at which to pour a mould. A like study of the molten character, combined with the temperature in a fluid state, will enable the moulder to judge as well in one case as the other, and this should be practiced more than it is, as no moulder or founder can tell when a knowledge of the former would not be as valuable as the latter.

Judging the grade of metal by its appearance in a fluid state is often done by experienced founders, and with a little study and observation the following description may often enable the inexperienced to soon become proficient in judging molten metal: A No. 1 or high graphite soft iron will generally present a lively vibration of different colors having the appearance of coming up from below the surface, forming an oxidized crust. This crust has the appearance of struggling to break away from alloys, which do not take kindly to being associated with a grey or soft iron. When No. 1 iron is slowly cooling down from a high temperature to a low one, it will often be unable to hold all its carbon in a combined state. What cannot be retained will gradually rise to the surface as graphite in the form of a scum or kish, and in the latter state will float away in the air, often covering everything near at hand with thin flakes of shining material, looking like silver lead or plumbago. These can properly be called pure carbon freed from the metal. Around blast furnaces, this latter phenomenon can often be seen, sometimes so active that the employes will be covered with "kish," making them look

like a fishmonger covered with shining fish scales.

When metal is high in silicon, its surface will have a smooth, dead appearance devoid of life, and if the surface is disturbed with a rod or skimmer, it will act a great deal like cream upon milk. Were it not for its dull, silvery, quiet appearance and sparkless action, it might often be taken for hard iron. No. 1 iron, whether high in free carbon or silicon, when running from the cupola into a ladle or from the furnace to the pig beds, throws off very few sparks, and those that do fly are chiefly caused by vibration of the metal from the running or spluttering of the stream, and fall as ordinary sparks, very different from those which come from harder or lower grades of melted iron.

Irons low in silicon and high in sulphur, from No. 4 to No. 7, which can be termed hard iron and also can be strong and weak, have peculiarities very pronounced to distinguish them from soft grades or No. 1 irons. In the ladle, such irons will, when "hot," show a smooth, bright appearance, with hardly a break on the surface, and as the mass becomes cool or "dulls down," it presents a dull, hazy, plastic appearance, which, if disturbed by a skimmer or rod, will act as if it were covered with an oxide or scum. While hot, it will often boil in the ladle as if bubbles of gas were escaping from below. It also emits many sparks, which is the chief characteristic phenomenon of hard iron and cannot be better explained than in the language of Tomlinson, who says:

> From all parts of the fluid surface is thrown off a vast number of metallic sparks, from the absence of carbon, which renders the metal sensitive to the oxidizing influence of the atmospheric air.

Small spherules of iron are ejected from all parts of the surface to the height of five or six feet, and sometimes higher, when they inflame and separate with a slight hissing noise or explosion into a great many particles of brilliant fire, forming oxide of iron.

The most difficult "grades" to judge of are Nos. 2 and 3, as they can often closely approach the appearance of No. 1 or the higher numbers. In closing this subject, the author would say that blast furnacemen can often tell very closely the "grade" an iron will show when cold by its appearance when fluid, and a more extended study of such phenomena by the moulder and founder will often prove valuable.

A practice followed by some of late years for determining silicon in fluid metal is one originated by S. A. Ford and first practiced at the Edgar Thomson Steel Works. The following description of the process is taken from Blair's "Chemical Analysis of Iron:"

To get the sample for analysis, a small ladle is dipped into the iron as it runs from the furnace and a small quantity of molten iron is taken. The ladle is then held about three feet above a bucket of water, at the same time giving the ladle a circular motion above the bucket. This will cause the iron to form in globules more or less round according to the amount of silicon contained in the iron. Thus, with iron which contains two per cent. of silicon or more, the globules will be almost perfectly round, concave on the upper surface, and generally one-quarter inch (6mm.) to three-eighths inch (9 mm.) in diameter; while if the iron be low in silicon the shot or drops will be very small, flat and irregular in shape, and if the iron be very low in silicon, as is the case with spiegel and ferro-manganese, the shot will be elongated and have tails sometimes one-quarter inch (6 mm.) in length.

Instead of the globules defining the percentage of silicon, the author would say that it would be better to specify results as "grades." By such a practice we

recognize the effect of all the metalloids in controlling degrees of hardness or softness to more truly define the character of iron from the formation of the globules of suddenly chilled molten metal.

The author has not presented the Ford plan as one feasible of application without a great deal of practice, but more to present ideas that may prove of value in other directions. There is this much to be said: that whatever methods a founder can utilize as being practical will at some time or other prove very beneficial, especially in "air furnace" workings and long "heats" in cupolas, for with the latter there is a chance given, if at the first tappings iron proves itself radically wrong, to then alter the charges in order to change the "grade" of the metal to come later on. Cases have been known where, through slack work or errors in "marking iron" when piled in the furnace yard, the analyses given belied the results found by the tests of re-melting, and were a cause of placing the founder "all at sea" in knowing what to do, besides making heavy losses in castings not coming the "grade" which they would have done had not the errors in marking the piles deceived the furnaceman as well as the founder in the true analyses of the iron. Experiences of the above character more than ever give the founder cause for exacting greater care and system in the piling, "marking" and shipping of iron at the hands of the furnacemen, workings which are in line with those discussed in Chapter XXXV., pages 284 and 295.

CHAPTER LI.

RESULTS OF VARIATION IN THE FLUIDITY OF METAL AFFECTING PHYSICAL TESTS.

Variations in the fluidity of molten metal are a factor which the author has discovered to be very important to note in considering the depth of an iron's chill, taken by means of a test bar or "chill block." It is a point which does away with past records or statistics which have been in any wise compiled from deductions taken from the depth of a chill, by the pronounced manner in which it asserts itself in giving evidence of being affected by the degree of fluidity at which a test bar is poured. In experiments with iron poured "hot" and "dull," the author has made the thickness of chill as much again in one case as in the other. Take, for instance, two test bars and pour one hot so that the iron will run up in the fluidity strips seen in Figs. 90, 98 and 99, page 496, about six inches high, and then cool the iron so as it will only run up about an inch: it will be found upon breaking the bars to test the chill that the hot-poured bar will have chilled about as much again as the dull-poured one. I have not accepted this principle as a fact from a test or two, but have made many to fully assure myself that the principle is correct.

The Tables seen on page 391 show the difference in chill by reason of "hot" and "dull" poured iron, in test bars 1⅛ inch diameter cast on end. It will be noticed that the fluidity of the hottest poured bar in Table 39 was but four inches, and the dullest one, one inch, a difference of three inches, but this was sufficient to make a difference in the chill of five-sixty-fourths of an inch, and this was the same iron poured out of the same ladle. A chemical analysis of the iron charged in the cupola and that obtained in the test bars is also given in Table 39. In Fig. 67, K shows the fracture of the hot-poured bar, and P the fracture of the dull-poured one, from which a good realization can be received of the effects different degrees of fluidity can cause in giving different depths of chill from the same iron poured out of the same ladle and which is forcibly shown by the Tables, page 391.

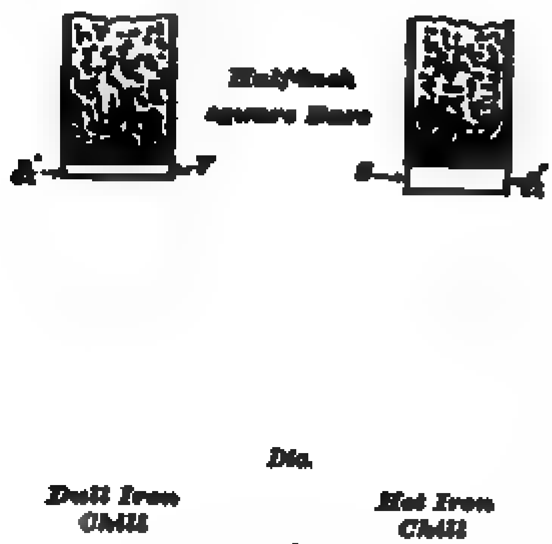


FIG. 67.

In the Table we find a difference of .032 inch in the chill of the two ½-inch bars which were poured out of the same hand ladle holding about fifteen pounds of metal. The first bar was poured as soon as the metal was carried to the "floor," and the second bar three minutes later. Here we find there is a difference in chill of .032, due to difference in fluidity of metal, or in rough figures $\frac{1}{32}$ inch, as seen at V and S, Fig. 67.

I state the time between the pourings to give an idea of how long the metal was held.

The fluidity strips are the practical guide to go by. Of what use is time in regulating or asserting the fluidity of irons between two foundries, or one heat from another? The iron in no two foundries is of the same fluidity, or for that matter the same foundry will seldom have two days' run in succession alike, and where one shop could only hold its metal for five minutes, another might do so for ten. There is no guide to register the fluidity of molten metal better than fluidity strips attached to test bars, as advocated by the author in Chapter LXVII. For scientific research and close regulating of mixtures by physical tests, it is essential for fluidity strips to be attached to test bars, where one desires to obtain true knowledge of irons or mixtures. I have shown that degrees in fluidity affect the depth of chill, also that it is incorrect for a test bar to pull away from its chill when contracting, as seen in Chapter LVI. This latter evil only the more aggravates the one caused by different degrees in fluidity, as both elements are effective in causing erratic depths of chill.

I could have shown a much more radical difference in the chill obtained from the same ladle by different degrees of fluidity, and would here say that in one case I found with the same iron in pouring two ½-inch bars that the dull-poured one had a chill of $\frac{1}{16}$ inch, the hot-poured one ¼ inch, a difference of $\frac{3}{16}$ inch.

For any that desire to test the question of degrees of fluidity causing different thicknesses in chill, in ½-inch square test bars, I have presented the plan I used in my experimenting with a ½-inch square test bar,

which is seen below at Fig. 68. In using this device to get two test bars, I moulded two separate patterns, in a flask large enough to admit them and having four inches of space between them, so that the gas or heat from the first poured one could not affect the other bar. The flasks were leveled so as to afford like conditions for the running of the metal into the fluidity strips. For chills at the ends of the test bars I used pieces of ½-inch square wrought iron rods, cut to a length of two inches, and loosely set them against the ends of the pattern when moulding. Should any one desire to cast two bars at the same time in one flask, they would simply require, of course, one gate, and it in the middle, leaving the fluidity strips on the outside of each bar. Fluidity-measuring testing tips, cast on test bars, are an entirely new departure originated by the author, and found by him to be of much value wherever reliable records are desired for comparisons of chill records, etc. The plan devised for using fluidity strips with test bars cast on end is described and illustrated in Figs. 95, 98 and 99, Chapters LXVI. and LXVII.

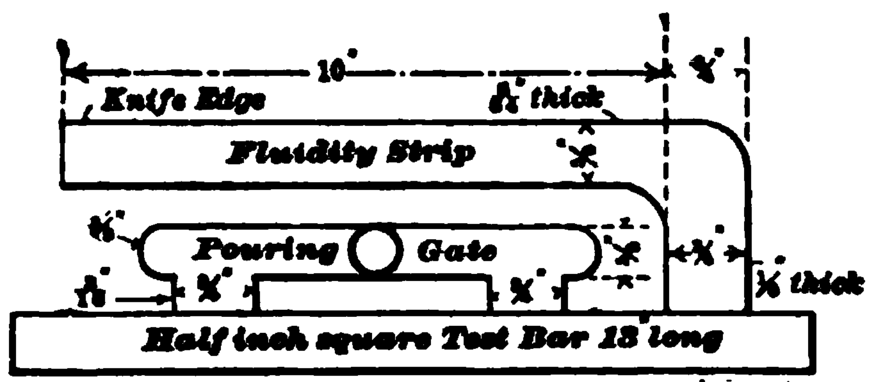


FIG. 68.

TABLE 39.—PHYSICAL TEST TAKEN WITH 1⅛-INCH ROUND BARS.

Micrometer Measurement.

No. of Test.	Fluidity.	Shrinkage.	Contraction.	Deflection.	Strength, broke in lbs.	Chill.	Diameter of test bar.	Strength per sq. inch in lbs.
1	4"	30	.156"	.120"	1,505	.172"	1.130"	1,501
2	1"	16	.156"	.110"	1,500	.094"	1.117"	1,531

Common Measurement.

1	4"	30	10-64"	7-64"	1,505	11-64"	1 8-64"	
2	1"	16	10 64"	6-64"	1,500	6-64"	1 7-64"	

Analysis of Pig Iron Charged.		Analysis of Test Bars.	
Silicon.	Sulphur.	Silicon.	Sulphur.
1.46	.039	1.26	.072

PHYSICAL TEST TAKEN WITH HALF-INCH SQUARE BARS.

No. of Test.	Fluidity.	Deflection.	Strength in lbs.	Chill.
1	1½"	.190"	300	.048
2	8"	.190"	290	.080

Analysis of Pig Iron Charged.		Analysis of Test Bars.	
Silicon.	Sulphur.	Silicon.	Sulphur.
1.82	.035	1.67	.056

CHAPTER LII.

SPECIFIC GRAVITY OF VERTICAL-POURED CASTINGS.

Below is given an extract from a paper by the author, read before the autumn meeting of the Iron and Steel Institute, at Birmingham, England, August 20-23, 1895:

Some authorities have asserted that a test bar cast on end, if placed on supports equidistant from either end, would not break at the point where the load is applied, but at a point an inch or so away from the point of pressure toward the uppermost cast end of the bar. In a long experience with bars cast on end, the author has failed to find any such condition. Indeed, he has not found any difference in this respect with bars that were cast flat or on end. With a view to thoroughly investigating the matter, he conducted the following experiment, and obtained the information given by the Builders' Iron Foundry of Providence, R. I., cited, and shown in Table 41, page 394. These are tests which the author first presented in a discussion on testing at the meeting of the American Society of Mechanical Engineers, held in New York City on December 3, 1894, and later gave them in a paper before the Iron and Steel Institute. In the first test of specific gravity, he wished to call attention to the fact that the specimen used was strictly a parallel gate test

bar. He mentions this fact for the reason that in the discussion above cited, one member of the American Society took the position that the specific tests on page 394 were inadmissible proofs to establish any principle, owing to the bottom end of the gun which was cast down being of a more massive nature than the upper end, and hence there was good reason to expect metal to be less dense in the bottom than in the upper end of the gun. The following test of the parallel gate which the author conducted shows the fallacy of the idea that the lower end of vertical-poured castings must be of a greater specific gravity than the upper end. In the experiment which the author conducted at his own foundry, he took a "gate" 6½ feet long and 3 inches in diameter, which had been used for pouring an iron ingot mould casting, and took a test-piece 6 inches from the top, and another 5 feet from the top. The gate was practically parallel, so that, in turning these specimens in the lathe, the same amount of surface was carefully removed from each. The specimens were machined of exact size, and were then delivered to the laboratory of the Case School of Applied Science, of Cleveland, O., to be weighed. The determinations (Table 40) reported by Prof. C. H. Benjamin were as follows:

TABLE 40.

Weight of top end of gate in vacuum	1169.468 grammes.
Weight of bottom end of gate in vacuum	1167.239 "
Volume of top end of gate	165.722 cubic centimetres.
Volume of bottom end of gate	165.768 " "
Density of top end of gate	$= \frac{1169.468}{165.722} = 7.0568.$
Density of bottom end of gate	$= \frac{1167.239}{165.768} = 7.0414.$

Difference=0.0154 only. The plug from the upper end is the denser.

Table 41 presents a series of tests on the specific gravity of vertical-poured gun castings.

TABLE 41.—TESTS OF SPECIFIC GRAVITY OF FIRST AND LAST SIX MORTAR CASTINGS.

Number of Heat.	Specific gravity of muzzle or top end of gun.	Specific gravity of breech or bottom end of gun.
78	7.238	7.2478
79	7.2436	7.2447
80	7.256	7.269
87	7.2934	7.2882
88	7.278	7.285
89	7.335	7 329
185	7.3263	7.3182
186	7.3325	7.3252
187	7.3404	7.345
188	7.3636	7.3336
189	7.349	7.340
190	7.3345	7.3267
Total	87.6903	87 6524
Average	7.3075	7.3043

The lower test disc was taken about 11 feet from the top of the casting and the upper test 2½ feet from its upper end. The majority of the tests showed the specific gravity of the muzzle specimens to be higher than the breech specimens and also to be harder and of higher tensile strength. This is the reverse of what many would expect. Table 41 shows the average specific gravity of all the casts made for specific gravity of breech and muzzle specimens on the first six mortar castings and on the last six mortar castings made by the Builders' Iron Foundry, from whom the author received these tests, and wishes here to tender his thanks for the kindness rendered.

The tests and figures in Tables 40 and 41 indicate that there is no condition which will cause any practical difference in the lower and upper end of long

vertically-poured castings, in the sense which has been generally accepted.

In considering the gun and gate tests of specific gravity in connection with those referring to the density of the lower side of flat-cast test bars being greater than the top side, discussed in Chapter LXV., it would at first seem as if the results were contradictory as far as they relate to the enunciation of any law or principle governing the quality of specific gravity in vertical-poured casting. The gate and gun tests show the upper end to have the greater specific gravity, and that of flat poured test bars to have the greater density in the side cast downwards. The latter is largely due to the bottom portion or surface of flat-cast test bars being most affected by the chilling qualities of the sand of the mould when it is filled with molten metal. If the specific gravity had been taken from the bottom surface of the gate test bar and gun castings, instead of a few inches in height from their bottom end, as was done, there might have been a difference found in favor of the lower end being the denser. This is, however, doubtful, as the gun and gate specimens had such a small area exposed to the mould's chilling influence, compared to the mass of metal comprising the castings. On the other hand, with test bars cast flat, the reverse occurred, and this is due to the fact that a fair percentage of the metal comprising the test bars is distributed over a large area of mould surface and is affected by the chilling qualities of damp sand, which is an unnatural effect that cannot be charged to specific gravity proper.

When the specific gravities of long vertical-poured

castings are tested a few inches from the bottom and a few inches from the top, the reason for finding the upper end the denser, as exhibited by the tests recorded, the author defines as being largely due to the law of metal expanding at the moment of solidification. Expansion tending to make the upper end of castings as dense as the lower may be better understood when it is stated that molten metal begins to solidify at the bottom of a mould and rises in height as the solidification continues. The effect of expansion at the moment of solidification, as castings "freeze" from the bottom upwards, has a crowding action, tending to make the molecules denser as height increases, and thereby to partly neutralize the effect in the difference of the specific gravity naturally expected to exist while the metal is in a fluid state. The author has obtained the following Table 43 of analyses of the top and bottom piece of the vertical-poured parallel gate test bar from E. D. Estrada, M. E., of Pittsburgh, Pa.:

TABLE 43.

	Carbon.	Phosphorus.	Manganese.	Silicon.	Sulphur.
Top piece.........	3.72	0.091	0.31	1.32	0.046
Bottom piece...	3.81	0.085	0.33	1.32	0.047

These results show that practically there is little difference in any chemical constituent that might tend to equalize the specific gravity of the two ends of the vertical-poured parallel gate test bar, and that we are left to accept the author's theory of such results being due to the principles involved in the law of expansion at the moment of solidification.

CHAPTER LIII.

EXPANSION OF IRON AT THE MOMENT OF SOLIDIFICATION.

The question of iron expanding at the moment of solidification was, up to a very recent date, affirmed by some and questioned by others. It remained for Mr. John R. Whitney, of Philadelphia, Pa., to first demonstrate in a practical way that iron truly expanded at the moment of solidification. This was fully verified by the author in experiments which he conducted immediately after Mr. Whitney published his results in the *National Car and Locomotive Builder* of May, 1889, of which the following is an extract, and by later experiments shown on pages 399, 402 and 424:

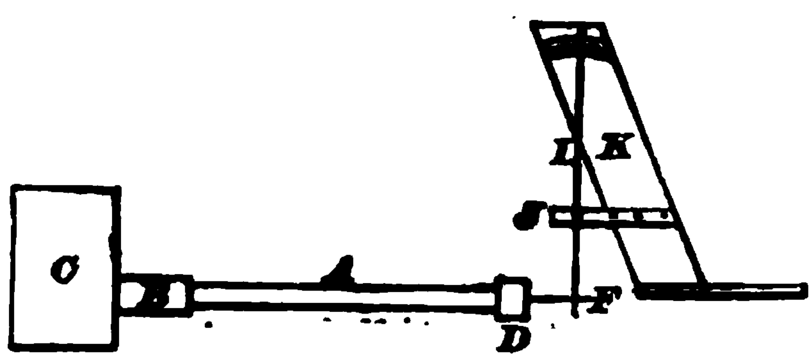


FIG. 69.

On a more recent occasion the following experiment was made with an apparatus more carefully prepared, as shown, Fig. 69. A pattern, A, 4 feet long, 3⅝ inches deep and 2¼ inches wide, was moulded in open sand; one end of the mould being closed by fire brick B, and the other end by a piece of gas carbon D, which was suitably connected with a small battery and galvanometer. The fire brick B rested at one end against a block of iron C, weighing about half a ton. The gas carbon block D was carefully secured in the sand, so that the

weight of iron in the mould should not be sufficient to move it. The stand K, bearing an arm J, on which the pointer I was delicately pivoted, was then adjusted so that the needle F should press against the gas carbon D, and the pointer stand at zero on the scale. The long arm of the pointer was 24 inches, and the short one 6 inches long, or as 1 to 4. The scale was graduated to 1-16 inch.

A, casting; B, fire brick; C, weight; D, gas carbon block; K, stand; I, pointer; J, supporting arm; F, adjusting needle.

The mould was filled with very fluid hot iron in 17 seconds, and then the following results were carefully noted:

For more than 1 minute after the mould was filled, pointer stood at zero.

At 1 minute 30 seconds after the mould was filled it moved 1-16.

At 1 minute 50 seconds after the mould was filled had moved ⅛.

At 3 minutes 10 seconds after the mould was filled had moved ¼.

At 5 minutes 20 seconds after the mould was filled had moved ⅜.

At 8 minutes 5 seconds after the mould was filled had moved 7-16.

At 11 minutes 30 seconds after the mould was filled had moved 15-32.

At 12 minutes 5 seconds after the mould was filled had moved ½.

From that time the pointer stood perfectly still at ½ inch until 25 minutes 15 seconds after the mould was filled, when the galvanometer showed that contact with the gas carbon was broken and contraction had begun.

I have made several other equally convincing experiments, but the length of this article forbids that they should be repeated here.

Long before these experiments were instituted the fact that iron follows essentially the same law as water in solidifying was well known and published. I need cite only two authorities: Prof. Edward Turner, in his "Elements of Chemistry," published in Philadelphia in 1835, by Desilver, Thomas & Co., says, page 20: "Water is not the only liquid which expands under the reduction of temperature, as the same effect has been observed in a few others which assume a highly crystalline structure in becoming solid; fused iron, antimony, zinc and bismuth are examples of it." Prof. Thomas Graham, also, in his "Elements of Chem-

istry," published in Philadelphia in 1843, by Lea & Blanchard, says, page 385: "Iron expands in becoming solid, and therefore takes the impression of a mould with exactness."

As the observation of this law was the basis upon which my experiments leading to the successful development of the contracting chill for cast iron car wheels was based, I am persuaded it will lead to many other practical results of great importance. This is my apology for trespassing upon your space and calling special attention to the matter.

The illustration seen in Fig. 70 is one the author displayed in the *American Machinist*, November 1, 1894, to prove that the practice of casting bars between iron yokes, etc., prevented free action of the metal in expanding.

FIG. 70.

A one-half-inch square test bar, twelve inches long, was used for an illustration. The author has tried by this device one-half-inch test bars without "gates," pouring them in "open sand" or without a cope, and cannot say he found much difference in their expansion. If any difference, the one with the gate showed the more. H is an iron block fitting tightly against the closed end of the flask. B is an iron block fitted loosely into a hole in the open end of the flask, as

shown. D is an arm of which there are two, one being attached to each side of the flask through which the pin A is inserted to give a fulcrum for the indicator arm E to revolve on as the one-half-inch square bar expands.

The length of the lever E is seventy-two inches at the long end and the short end should read one and one-quarter inches instead of two inches, as shown. The dotted line of the indicator shows what the arm moves at the time of expansion. It measures about one-half an inch, sometimes going over this mark, and sometimes a little under it, thus disproving the logic that small bodies or test bars will not expand, as claimed by some. It makes no difference how large or small a body is, the same law is effective in all cases of metal cooling from a liquid to a solid body.

By referring to Chapters LIV. and LV., pages 413 and 425, two other devices originated by the author for recording expansion can also be seen. These devices present expansion tests which show the reason for there being no practical difference in the specific gravity of the two ends of vertical-poured castings, as can be seen in Chapter LII., page 396. Then again, by referring to Chapter LIV., page 407, the effects of expansion in causing shrink holes in castings are fully outlined.

CHAPTER LIV.

THE EFFECT OF EXPANSION ON SHRINKAGE AND CONTRACTION IN IRON CASTINGS.*

The fact that iron expands when heated, until fusion takes place, and that molten iron is consequently less dense than solid iron of the same grade, is now universally admitted. It was proved by the extensive experiments of Mr. Thomas Wrightson, reported in the first volume of the *Journal of the Iron and Steel Institute* (1890 and 1891), and, in a manner, is illustrated in heavy founding by the shrinkage of the molten metal, which must be "fed" in order to obtain solid castings.

This decrease in volume requiring "feeding" while the metal is still liquid I call "shrinkage" (see pages 409 and 410), applying the term "contraction" to the decrease in volume which takes place after solidification, while the iron is cooling to atmospheric temperature. The light-work founder, not having the opportunity to make heavy castings, in which shrinkage can be observed, is apt to confound the two; but they are in fact distinct, and are separated by an act of expansion, which takes place at the moment of solidification.

(Contribution by the author to the Discussion of the Physics of Cast Iron, at the Pittsburgh Meeting, February, 1896.)

The fact of this expansion was first practically demonstrated by Mr. John R. Whitney, of Philadelphia, Pa., whose experiments are recorded in the *National Car and Locomotive Builder* of May, 1889, and cited in Chapter LIII., page 397.

Experiments recently made by the writer indicate that there is a constant relation between this expansion and the preceding shrinkage and forcibly demonstrate the necessity of "feeding" a casting to make its interior solid. This is a matter with which all makers and users of castings have experienced difficulty. The founder being heretofore unable to define correctly the principles involving the urgent necessity of "feeding," has failed to impress the moulder with its importance in making sound castings. Heavy-work founders and moulders know that hard grades of iron shrink much more than soft grades, a fact for which no satisfactory explanation has heretofore been given.

By recent expansion experiments I have discovered that hard grades of iron expand more at the moment of solidification than soft ones. Fig. 71, page 404, is a diagram recording four such experiments.

The manner in which the automatic records were obtained will be described further on. It is sufficient to say at present that the scale of inches in the diagram measures the length of travel of the pencils on the long recording-arms of the apparatus employed, not the actual length of expansion. The end of the short arm of each lever, following actual expansion, travels $\frac{8}{32}$ inch for 1 inch traveled by the pencil, and the length of the test bars being 48 inches, 1 inch of the expansion or contraction record represents an actual expansion or contraction of 3 in 1536, or 0.195

per cent. For the purposes of these experiments, however, the actual expansion or contraction was not required.

The significance of these diagrams is qualitative and comparative; and for this use of them the reading of the pencil-travel in inches is accurate, the apparatus and operation being the same in all the tests recorded. With this explanation I return to Fig. 71. In each of the four casts shown, two test bars, 1 x 1¼ inches in section and 4 feet long, were cast "open-sand" side by side in the same mould. Tests Nos. 1, 3, 5 and 7 were poured from the respective ladles which brought about 100 pounds of the iron direct from the cupola. These tests comprised the softest iron of each cast and had the least expansion and contraction, as is shown by the diagram. For tests Nos. 2, 4, 6 and 8, the grade of the iron was changed, by means of pouring about half of the hundred pounds contained in the ladle coming direct from the cupola into an empty ladle, the bottom of which was covered with about three-quarters of a pound of brimstone. The metal in the ladle having the sulphur was then agitated with a half-inch wrought iron rod until fuming ceased, after which all dross was skimmed from the surface, when each ladle was poured into its respective test-mould. The addition of sulphur hardened the iron in these tests, thereby causing the increased expansion and contraction shown in the diagram.

In Fig. 72, page 405, tests Nos. 9 and 10 illustrate another discovery made by this method of comparative tests, namely, that where free expansion is prevented, a greater contraction is effected.

Test bar No. 9 was cast between iron ends, so ar-

ranged that the power of expansion was not sufficient to extend the distance between them, whereas No. 10 had sand ends to compose the mould, which gave full freedom for expansion, the same as in all other tests displayed in Figs. 71 and 72. The fact that hard

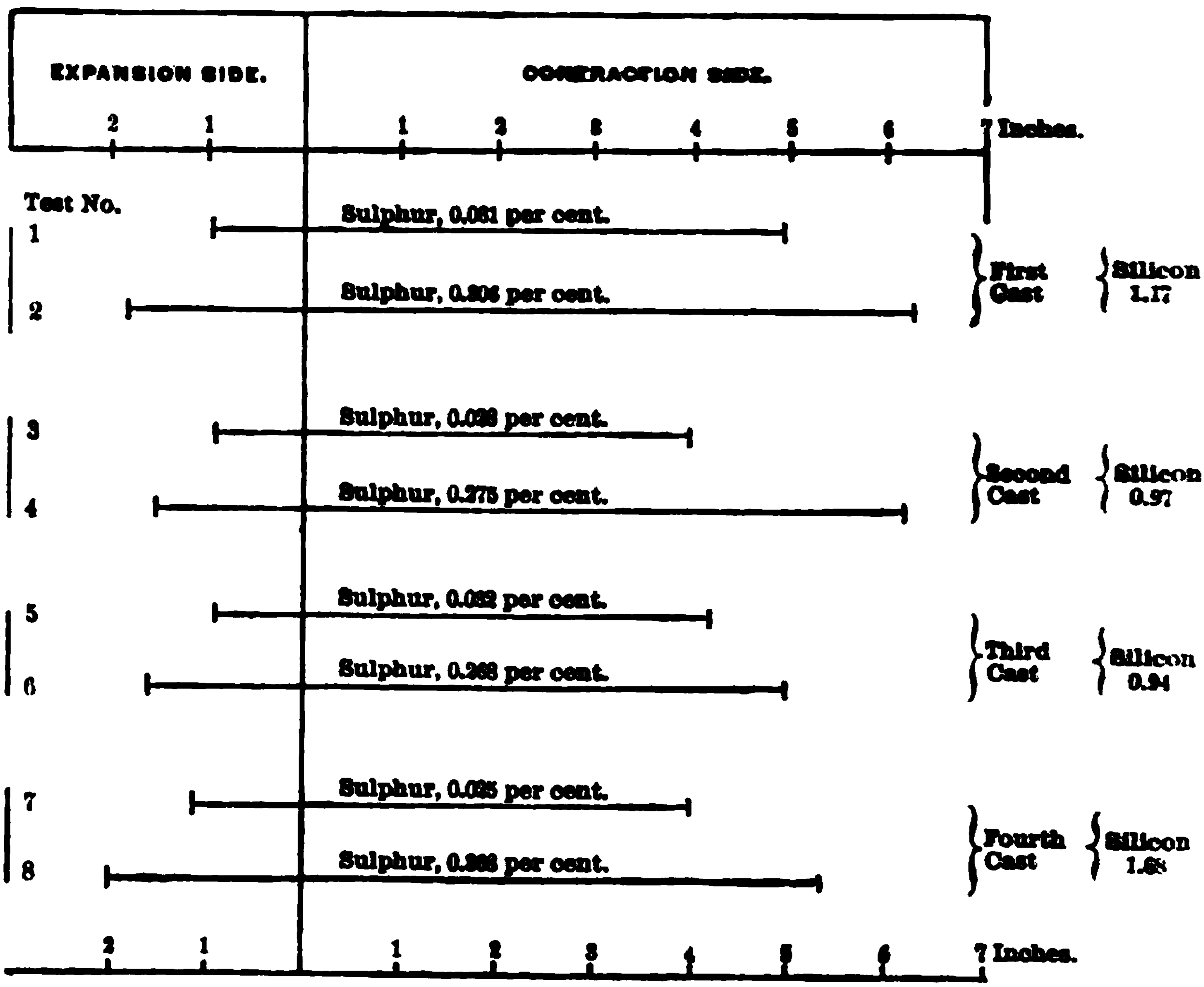


FIG. 71.—DIAGRAM FROM AUTOMATIC RECORDS OF EXPANSION AND CONTRACTION, VARIED BY ADDITIONS OF SULPHUR.

grades of iron expand more than soft ones, and the fact that retarding expansion gives rise to a greater contraction than where free expansion is permitted, are important as suggesting for works making such specialties as chilled rolls, car-wheels, etc., in which heavy

losses are often experienced through chill-checks and cracks, the advisability of adopting expanding and contracting "chills" wherever this may be practicable.

Tests Nos. 11, 12, 13 and 14, in Fig. 72, illustrate the expansion and contraction of different sizes of bars poured in pairs from the same iron. These tests show

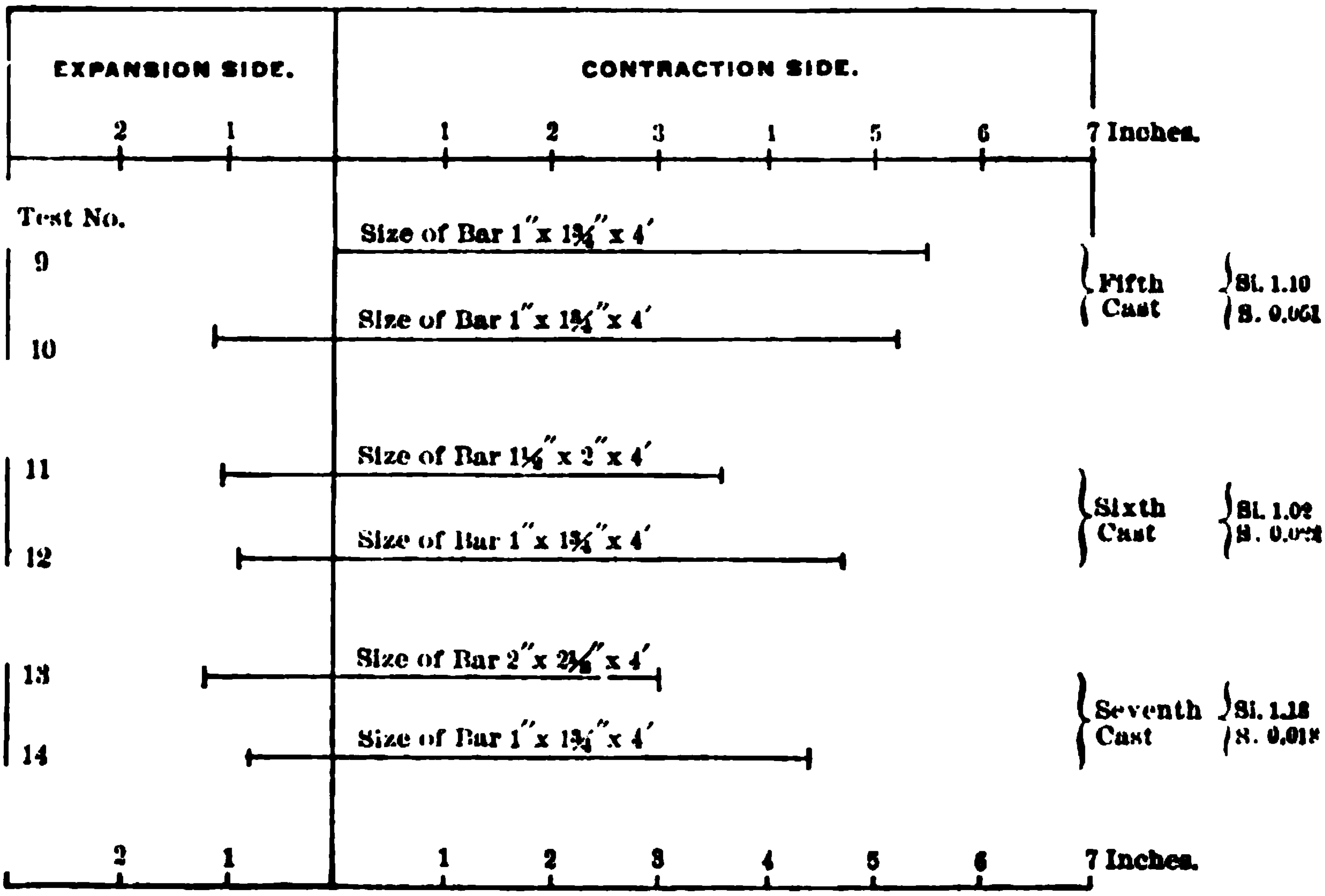


FIG. 72.—DIAGRAM FROM AUTOMATIC RECORDS OF EXPANSION AND CONTRACTION, VARIED BY CONFINING EXPANSION AND BY USING BARS OF DIFFERENT SIZES.

that large bars expand so as to increase their interior space more than small ones, thereby calling for the greater "feeding" in massive castings. These tests indicate also that light bars contract more than heavy ones, an element not to be overlooked in proportioning casting so as to avoid internal strains so far as practicable, a quality also seen on page 421.

The "open-sand" method of casting test bars affords the means of making comparative tests under varied conditions and gives an excellent opportunity to observe characteristic phenomena at the moment of solidification, etc. In casting test bars of hard iron, a pronounced shrinkage along the upper surface is often noticed during the period of expansion; and often before expansion is over there may be seen through shrink-holes at the hottest part of the bar (namely, at the point where it was poured,) that the interior is still liquid, showing that it is not necessary that the whole body of the casting shall solidify before expansion takes place. In this phenomenon, we perceive also the simultaneous action in the casting of two opposite tendencies, shrinkage going on in some parts, while expansion is occurring in others.

It is the general impression among moulders and founders that the hotter the iron is poured, the more it will shrink, that is, the more the casting will require to be "fed." This is an error into which the moulder has fallen by reason of the longer time occupied in the cooling or shrinkage of the "hot"-poured metal, and consequently the longer period of "feeding." The total addition of iron required in the "feeding-heads" is no greater with "hot" than with "dull"-poured iron, unless the "hot"-poured metal has more largely penetrated, fused or strained the walls of the mould.

Numerous experiments have failed to show me any effect produced upon the total expansion by changes in the temperature of the metal when poured. Such an effect would not be naturally expected, since the expansion begins only with solidification, and the temperature of solidification, it is reasonable to say, is

always the same for the same grade of iron, under the conditions of these tests; so that, however "hot" iron may have been poured, it will always have a certain temperature when it begins to expand. But it is, of course, clear that expansion will take place sooner in a "dull"-poured bar than in a "hot" one; and again, a light body will expand more quickly than a heavy one, as I have proved by my tests.

The length of the period of expansion varies with the size of the casting. The more massive the casting, the longer the period of expansion. For the bars shown in Figs. 71 and 72, the expansion lasted from one-half to one minute in the smallest bars, and, in the largest bars, from three to five minutes. The relation between the shrinkage and the expansion of solidification may now be indicated. The author's view is that the apparent shrinkage of liquid metal so familiar to heavy founders is not due chiefly to a change in the specific gravity of the liquid metal as it passes to a solid state, but largely to the effect of the expansion of the solidifying parts of the casting. That is to say, an outer shell of the casting being first formed, its expansion at the moment of solidification necessarily enlarges the interior space to be occupied by liquid metal; and either additional liquid metal must be applied or else cavities and shrink-holes will be found in the interior of medium and heavy castings, by reason of the progressive accretion of the solidifying metal upon the parts already solidified. Such cavities would, on this hypothesis, be likely to be most abundant in the portions which solidify last; and that this is in fact the case, is often proved by practice. Cavities are very liable to occur in the interior of

massive castings, and even when castings are properly proportioned the portion around the "gates" which convey the metal to the mould is often very likely to be porous or to exhibit shrink-holes, due to the circumstance that the metal solidifies last at these points, and to the attraction of solidifying particles to the already solid mass. This hypothesis explains also the fact that, in heavy castings, poured "hot," shrinkage is not often exhibited in the "feeding-heads" until long after the pouring, and that when it does commence (which is not before some expansion has taken place, due to parts solidifying,) it is often so rapid as to require, for a short period, constant additions of molten metal.

Expansion at the moment of solidification being thus the cause of shrink-holes in castings, the practice (not uncommon among moulders) of placing "risers," not much larger than lead-pencils, so to speak, on massive castings, thinking thereby to make them solid, is to be discouraged as useless. It follows, moreover, that a casting should be "fed" until expansion is ended. It is not while a metal looks "hot" or fluid in a "feeding-head" that attention is specially necessary to secure a solid interior; it is when the metal is thickening or "freezing" in the "feeding-heads" that the greatest attention should be paid to the "feeding." It is a general practice among moulders, at present, to let their "feeding-heads" "bung up" at a time when the greatest effort should be made to keep them open, so as to insure a solid casting. It is at this time that expansion is taking place, to enlarge the surface area, and consequently the interior volume of a casting, thereby causing the hottest or most fluid

portion of the casting to be robbed of metal, which must be supplied, in order to prevent shrink-holes at all such points.

According to the view here presented, it will be also easy to understand that the resistance offered by the mould may often effect the expansion and shrinkage as well as the subsequent contraction. Whether the power of expansion is as great as that of water in becoming frozen, is, as far as I know, undetermined. I do know that by casting between iron yokes or flask-ends, the longitudinal expansion of the bar may be prevented, as is seen in Test No. 9, Fig. 72. In such a case, of course, it is natural to suppose that the expansion must be in some other direction, and it may increase to a smaller degree the interior space necessary to be supplied with molten metal by feeding. The heat-conducting capacity of the mould, as determining the rate of solidification, may also effect the apparent result. Thus, a casting made in an "iron chill" mould may show less shrinkage than if the same iron had been poured into a sand mould, because, in the latter case, the solidifying iron could have time and opportunity, by reason of the nature of the mould, to more expand it outward, thus increasing the interior space to be supplied with molten metal as already explained.

To return to the fact discovered by the writer, that hard grades of iron expand in solidifying more than soft grades, it may be said that this is contrary, not only to the general impressions, but also to the current explanation of the fact of expansion, which would ascribe it to the creation of graphitic carbon. If this were the controlling cause, we should ex-

pect soft irons, which exhibit after solidification more graphite, to show the greater expansion.

The formation of graphite is confessedly promoted by silicon, and hindered by the metalloids which "harden" the iron. When these metalloids are present in such proportions as to overpower the effect of the silicon, combined carbon, instead of graphite, is produced in the solidified metal, and the individual grains, crystals, or structural elements of the cast iron are consequently smaller and more densely packed in hard than in soft grades of such iron. Expansion (and, perhaps, also contraction,) would be, therefore, exhibited by a larger number of such structural elements in a given volume of metal, to be effected by changes in their form and size. This may explain the greater expansion shown by the hard grades in Tests Nos. 2, 4, 6, and 8 in Fig. 71, where the largest percentages of the antagonistic constituents, silicon and sulphur, are presented.

But any theory on the subject may be premature. Far more important at this time is the fact itself, which affects so directly our foundry practice. I attribute the failure to detect it heretofore to the circumstance that in the every-day work of the founder, the expansion of solidification does not force itself upon his attention. The shrinkage of the liquid mass, requiring "feeding," is obvious enough; and so is the final contraction of the solid mass, for which allowance has to be made in the pattern. But the intervening expansion, not being marked by the final contraction, has been overlooked.

I may here observe that the tests illustrated in Fig. 71 refute the opinion heretofore advanced, that the

silicon contents of an iron can be defined from the final contraction of a casting or test bar. In all the bars of each cast in Fig. 1 the silicon percentage was practically constant. The variation in contraction, therefore, certainly justifies the assertion that the amount of silicon cannot be thus determined. In fact, the contraction will simply indicate the "grade" of an iron, and no more. The metalloids producing this "grade" can only be determined by analysis.

The "grade" of a cast iron, as I use the term, is a practical name, familiar to heavy founders, though perhaps not capable of precise scientific definition. It is characterized by the degree of hardness, and incidentally by accompanying properties of contraction and of strength. This question of "grade" is further discussed in Chapter XXXIV., page 282.

It has been maintained that it is difficult to make cast iron absorb sulphur and that the founder has no need to fear sulphur in general founding. In the tests shown in Fig. 71, the amount of sulphur in the iron was easily increased by the method described, as is proved by the subsequent analysis. At all events, I feel sure that up to 0.3 per cent., sulphur can be easily present in cast iron containing about 2.00 per cent. of silicon, which is a percentage of silicon often permissible and practicable as a maximum in light castings, where the sulphur can be kept below 0.06 in the castings produced. As 0.2 per cent. of sulphur is sufficient to injure or ruin almost any casting made for other purposes than sash-weights, the ability of cast iron to absorb as high as 0.3 per cent. of sulphur forcibly illustrates the great reason which the founder has to fear sulphur in fuel, high-sulphur iron, and to

avoid any method in melting, favorable to the absorption of sulphur by iron in cupola or "air furnace" practice. These considerations are applicable also to the making of iron in the blast furnace.

The apparatus used for obtaining the expansion and contraction records, shown in Figs. 71 and 72, is shown in Figs. 73, 74, 75 and 76, pages 413 to 417. It was designed after much study of the conditions necessary for automatic record of the expansion and contraction of test bars, and also for the highly important purpose of simultaneous comparative tests.

The figures illustrating this apparatus (which is freely offered for use to all who may be interested in the matter) will be readily understood, with the aid of the following explanation:

In Figs. 73 and 74 the same letters indicate the same parts, namely:—

A, stationary or sliding recording face-plate board; B, float; D, float-receptacle; E, regulator, giving constant head of water; F, supporting arm for the water-supply vessel; H, over-flow pipe; K, L and M, recording arm levers; N, lead-pencil recorder; O, rubber-band lever-supporter; R, curve-recording face-plate board; S, slide-guides for recording curves; T, revolving sheave-wheel guide and support; U, fulcrum cross-bar; Y, supporter of fulcrum cross-bar.

In Fig. 75 the parts are indicated by letters, as follows:

A, counterbalance clock-weight; B, bed-plate, securing the base board; I, one-day "Pirate" alarm-clock; R, curve-recording face-plate board; S, removable casting-pin; U, fulcrum cross-bar; V, clock and recording face-board connecting-shaft.

FIG. 73.—AUTOMATIC RECORDING APPARATUS FOR EXPANSION AND CONTRACTION.

In Fig. 76 the parts are indicated by letters as follows:

A, expansion and contraction-end equalizer; B, spring-clasp; D, flow-off recess; E, spring-clasp iron; F, lever-fulcrum bearing; H, casting-pin clasp-opening; K, removable casting-pin.

The levers of this apparatus are so delicately mounted as to be moved by a breath. As already stated, for every inch travel of the long arm, the short arm, moved by the actual expansion or contraction, travels three thirty-seconds of an inch in the straight line. The diagrams, Figs. 71 and 72, pages 404 and 405, were constructed by platting the sum of the readings given by the pencils at the two ends of the apparatus in straight lines, and consequently give only the total longitudinal expansion and contraction, without indicating rate or alternations. But the apparatus can be employed, with the aid of the float or clock, etc., shown in the figures, to record curves. For a straight line record, the face-plate, A, Figs. 73 and 74, is held stationary. To obtain curves, it is gradually lowered at any desired rate by means of the float B, in the receptacle, D, Fig. 74, a constant head of water being maintained in the reservoir, E, by a supply from a suspended vessel at F, and an overflow-pipe. H. A specially arranged strong spring clock might be used instead of the float B, to lower this face-board uniformly, so as to effect the same end, and with either plan introduce into the results the element of time. Incidentally, such experiments ought to settle the question whether there are, as has been declared, two periods of expansion for cast iron when it is cooling, after the liquid metal has "frozen," or solidified.

FIG. 74.—AUTOMATIC RECORDING APPARATUS (SEEN FROM OPPOSITE SIDE OF FIG. 73), WITH ARRANGEMENT FOR RECORD IN CURVES.

The lever-arms, K, L and M, Figs. 73 and 74, are held gently against the face-plate by light rubber bands, secured midway in their lengths at O, so that the very soft pencils at N may record all movements of these arms. The pencil-record may be made on paper, covering the face-plate, as indicated in the figures, or on the bare face of the recording-board.

It will be evident that the records of the independent levers at each end of the bar must be added together, in order to determine the total expansion or contraction. Thus, in the case of test No. 1, Fig. 71, the

FIG. 75.—INDEPENDENT DIAL FOR RECORDING EXPANSION AND CONTRACTION IN CURVES.

automatic record of the apparatus would show a travel in expansion of one-half an inch at each end, or one inch in all, followed by a contraction of two and one-half inches at each end, or five inches in all, not including the retracement of the previous expansion. In other words, after expansion was ended, the bar contracted longitudinally eighteen thirty-seconds of an inch (each inch of the pencil-line representing

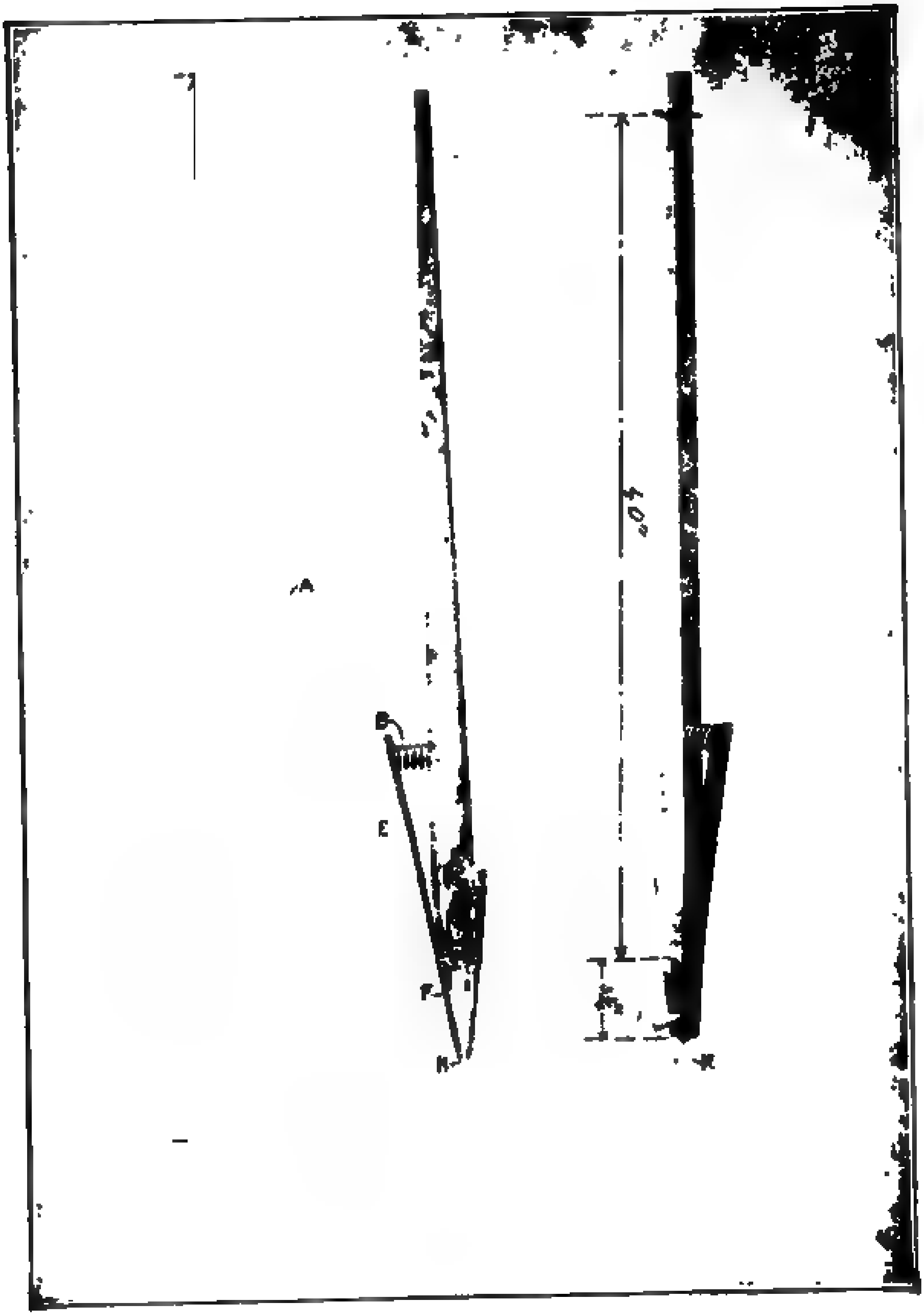


FIG. 7[illegible].—TEST BAR PATTERN AND LEVERS FOR RECORDING APPARATUS.

three thirty-seconds of an inch of the short-arm lever-movement, i. e., of actual extension of the bar); and consequently, the test bar, 48 inches long as poured, was elongated in solidification to $48\frac{8}{32}$ inches, and then contracted in cooling to $47\frac{1}{32}$ inches, its final length at atmospheric temperature.

The clock shown at I, Fig. 75, with its face-plate, R, can be set independently, with a single recording-lever, to receive on the revolving face expansion and contraction curves from one end of the bar only, or it can be supported, as shown in Figs. 73 and 74, so as to record curves in connection with the records made on the stationary or sliding face-board, A.

The whole apparatus is of wood, except the fulcrum bars, U, Figs. 73, 74 and 75, the casting-pin, S, Fig. 75, and the pin-holding plates, E, Fig. 76. From a study of these levers in Fig. 76 it will be seen that a little pressure on the spring-side at B will instantly release the casting-pin seen at K. The $\frac{3}{8}''$ casting-pins seen at S, Fig. 75, and in position at K, Fig. 76, are made tapering, so that they can be readily moved from a test-bar and used again. They cause the levers to record sensitively any movements due to expansion or contraction after the bars are poured. At the left of Fig. 76 is seen the form of pattern used for moulding the test bars. The projection at A is cast on, as shown, so as to insure equal action in recording the expansion and contraction at each end of the bar. At D is a recess, which gives guide to make the same in the mould, so that in pouring the bars "open-sand," the metal will "flow off" at this point when it comes to that level, and thereby insure all bars being cast closely to the same thickness.

CHAPTER LV.

STRETCHING CAST IRON AND ELEMENTS INVOLVED IN ITS CONTRACTION.*

What shall I allow for contraction? is a question which the experienced pattern-maker will generally ask the moulder or founder before any patterns of importance are begun. It is true, we have the stereotyped rule of allowing one-eighth of an inch per foot for contraction, and many pattern-makers and founders are so inexperienced as to accept such a rule for the contraction of every form and thickness of a pattern which their plant may be called on to make. It is possible with the class of work which they make that such a practice may never have led them into difficulties, and hence they obtain an experience which would lead them to believe that there are no conditions calling for anything else than the making of all patterns one-eighth of an inch per foot larger in every direction than the castings desired.

Moulders and founders of broad experience in general machinery work know that there will generally be a difference in the contraction on any two forms that differ in their proportions, even when poured with the same iron. Also the form of a mould and

* Read by the author at the meeting of the Western Foundrymen's Association, at Chicago, Nov. 20, 1895.

the manner in which it is made and the casting is cooled, have much to do with the size of the casting, as compared with the pattern from which it was made. It is not the intention of the author to attempt to set up any fixed rules for the contraction of castings by the classification of the different kinds of work, as some have done, for this is not practical, but more to call attention to the principles involved and assist the engineer, founder, moulder and pattern-maker to best judge what contraction, if any, should be allowed in constructing patterns, to meet the various conditions in moulding, mixing of metals and cooling of castings. Not only has the experienced heavy-work founder found a great difference to exist in the contraction of the same kind of iron in different castings, but some will agree with the author in affirming that instead of allowing for contraction, the reverse conditions occasionally prevail and are elements frequently necessary to be considered in making patterns. It is nothing unusual for moulders and founders engaged in heavy or jobbing machinery to find their castings to be larger than the patterns from which they were made, thus disclosing a condition in founding of which the light-work founder and "stove plater" would have no opportunity of attaining any knowledge. Before the author will discuss the qualities involved in stretching cast iron, which is an important part of this paper, he will consider those effecting a difference in thick and thin bodies cast under the same conditions or in the same flask with the same iron or "gates" and from which observing founders have learned that a heavy casting or parts will contract much less than a light one, where conditions permit of free contraction.

An experiment which the author conducted to demonstrate the fact just cited was to take a pattern 14 feet long by four inches by nine inches, and another exactly the same length but only one-half inch by two inches, and cast both together with the same gates. Although the bars were of the same iron, a difference of seven-eighths of an inch existed between their contraction. The thin casting contracted one and three-quarters of an inch, whereas the thick only went seven-eighths of an inch. Why is this? is a natural question to be asked, and in answer the author would offer the following hypothesis:

The carbon held in fluid iron, authorities claim exists in a combined form. How much of this will change to graphite when the castings or iron has solidified and become cold enough to handle, depends first upon the time of cooling, and second, the percentage of sulphur, silicon, manganese, and phosphorus, which exists in the iron. The greater the silicon up to about four per cent., also the phosphorus up to one per cent., and the lower the sulphur and manganese, taking account also of the time consumed in cooling, the higher we will find the graphitic carbon. The greater the formation of graphite, the larger the molecules and grain of the iron; and this is one secret of thin castings and hard iron contracting more than thick castings and soft iron, in cases where all conditions in moulding, cooling and freedom for contraction are substantially alike. For other qualities effecting this, see pages 282 and 443.

Two castings from one pattern, of the same iron, can, by cooling one more quickly than the other, be made to show considerable difference in their contraction, ow-

ing to the one having a greater time than the other to change the combined carbon to graphite, a quality the author noted in a paper before the Foundrymen's Association at Philadelphia. See Chapter LIX., page 444. This Chapter also presents analyses of one-half inch and one inch square as well as one and one-eighth inch round test bars poured from the same ladle at the same time, showing that the graphite was much less in the one-half inch than in the one and one-eighth inch test bars, and on this account contraction was much less in the larger than the smaller bars.

The formation of graphite may be compared to the raising of bread. The longer time given for the yeast to act, the greater the bulk of the dough obtained, caused by the expansion of the wheat's molecules. This is similar to the cooling of liquid iron to a solidified cold state. The longer the period for cooling, the greater the expansion of the molecules and grain of the iron, which is defined chemically by our having higher graphite in slow than in fast cooling; this is also assisted by the heaviest parts of a casting or that last to solidify often containing silicon to have its percentage higher than will be found in the lightest portion or those first to solidify. (Expansion is also a quality affecting contraction which should be considered in connection with graphite. For effects of expansion, see Chapter LIV.)

We can take the worst kinds of scrap iron, and by pouring them melted into heavy bodies, as anvil blocks, for example, obtain iron that presents a large, open-grained fracture, often of excellent texture, proper for being readily machined; whereas, were the same iron poured into a casting under three inches

in thickness, it would be "white" and hard as flint. In the former case, also, it would show much less contraction than in the latter. These facts will go to show that the length of time occupied in cooling a casting, after the molten metal has solidified, may often be more effective in causing different degrees of contraction and hardness of iron in a casting from ordinary used foundry iron, than any varying percentages of sulphur, silicon, etc., which exist in ordinary foundry iron. Any one giving due consideration to the points here raised will be led to concede the impracticability of formulating set rules for the contraction of castings, to be published as a universal guide to desired results in the dimensions of castings; but by a study of the phenomena here referred to, we will be in a fair position to determine what allowance should be made for contraction, etc., when we are on the ground of action. It is to be understood that reference is not made to the difference which may exist in the size of like castings from soft and hard iron, or variations due to the hardness of ramming and head pressure of molten metal on moulds, etc. We are mainly dealing with the elements involved in the question of contraction, as affected by rapidity of cooling, stretching of iron, and variations in the thickness of metal, etc., in castings.

Stretching is possible and due to influences exerted by conditions in casting, cooling, and forms of patterns, which overcome or retard free contraction. It can make castings larger than the patterns from which they were made, and it also makes it possible to obtain acceptable castings which could not be secured were it not for the ability of iron to be stretched.

The author will now describe a device which he has designed and originated to test and prove that cast iron stretches as well as expands. While the cuts 77 and 78, pages 425 and 426, will explain clearly to some the exact working of the device, I will describe it in detail in order that all interested can criticise and fully understand its construction and action.

A, Fig. 78, is the pattern used. The shoulders at B and C are for the purpose of providing means to stretch the bar by clamping or holding one end to a support at D, Fig. 77, which has a recess forming a part of the iron frame at the end D into which the projection X of the test bar pattern A is inserted when moulding the bar, and which when cast rigidly prevents the test bar from contracting or pulling away from this end, the other end being pulled by weights as seen at H where one, two or more 50-pound standard weights are suspended over the roller H. There are two moulds cast side by side, "open sand" with independent runners R and T from the same ladle of iron as quickly as they can be poured. The only difference existing in these two moulds, lies in one being strained by the weights, while the other is free from any weight or restraint to prevent contraction, other than the restraint of the mould's sides, and this affords the most favorable arrangement to observe and record any difference which may exist in the contraction, etc., of free and restrained bars. Independent pointers are attached to these bars by means of levers and show their readings on scales behind them.

The first movement of the pointer to be noticed is its passing to the right of zero. This action commences about 30 seconds after the bars are cast and

FIG. 77.—WEST'S STRETCHING RECORDER.

continues for about 90 seconds for a total travel of the pointer of about one and one-half degrees on the arc shown over the top of the pointer P. This is caused by the expansion of the metal at the moment of solidification, a quality, by the way, which some have disputed. After the expansion has fully recorded its influence, in lengthening the bar, the pointer P stands still for about two minutes, after which time contraction begins and the pointer P starts to move back to the left. The weights at E are now suspended, and it will be well to emphasize the fact that they exert no influence

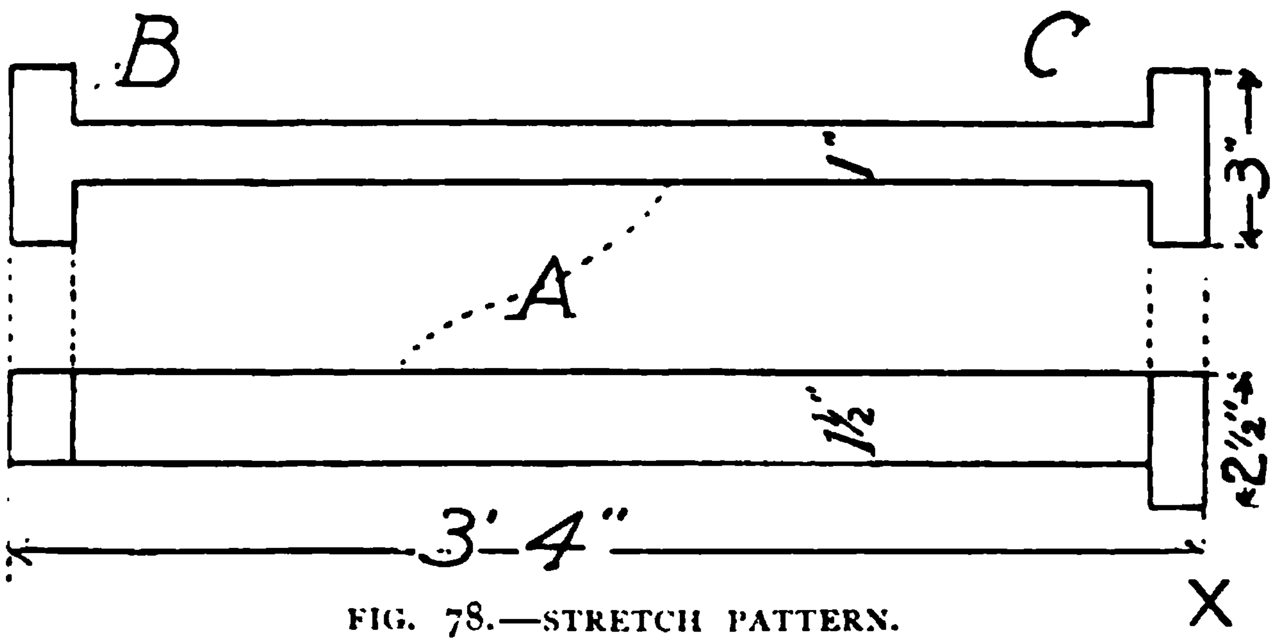


FIG. 78.—STRETCH PATTERN.

to suddenly move backward to zero the pointer P. Five minutes after the contraction commenced, the restrained bar's pointer will have moved about one degree and the pointer on the free bar two and one-half degrees to the left of their starting points. About fifteen minutes after the bars are poured the restrained bar will have moved the pointer one and one-half degrees and the free bar three and one-half degrees. At 30 minutes after the pouring, the restrained bar will have moved the pointer three degrees, and the free bar about five degrees, showing in the interim be-

tween 15 and 30 minutes after the pouring that the restrained bar held about even pace with the free bar.

From this point on, the restrained bar keeps gaining on the free bar, until the end, when the free bar stands about one and one-half degrees ahead of the restrained or weighted bar's pointer, thus showing we can restrict contraction by power and that the period of the greatest stretching of cast iron, cooling from a solidified state to the temper coldness of the atmosphere, wherever there is any restraint upon its contraction, is that ranging from 1,600 degrees F. to 1,200 degrees F., or in color from a light to a dark cherry.

The reason for describing the above tests in the manner detailed is owing to the fact of a low silicon mixture being used with but two 50-pound weights suspended to retard the contraction. Many other experiments were made, as will be shown further on.

In closely watching the movements of the pointers of the restrained and free bars as they contract, a wavering, quick, forward (and often backward) motion, sometimes as far as one-half degree, will be plainly noticed in the restrained bar, while the free bar has a constant steady forward movement. The quick, wavering motion is occasioned by the resistance to free contraction, which the weights offer to the bar, and occurs when the contraction occasionally has sufficient power to overcome the influence of the weights to stretch out the cooling iron. The fact that cast iron can be stretched is also often exemplified in heavy founding and in the cooling of castings, examples of which in every-day practice the writer will cite further on.

A factor not to be lost sight of at this point is the positive manner in which the device here described demonstrates that there is a moment of expansion in molten iron cooling down to a solidified state. To demonstrate this by the device shown, it is necessary to cast one bar between fixed iron ends which cannot be moved apart by the strain of the expansion, and another bar which shall have the end at the pointer P free in the sand to record any expansion which may take place.

Any one experimenting in this manner will find that the bar left free to expand will move the pointer to the right of zero from one to two degrees, while the bar cast between the iron ends or yoke will not move the pointer until it starts to the left, thus showing that iron will expand if left free to do so.

The author wishes to state that he is of the belief that with such a device as herein shown he will eventually be able to utilize the expansion of metal to denote the grade of hardness, etc., in the short period of one minute after the molten metal has been poured. There are several ways in which such a quick determination of the grade, etc., of metals could be practically applied and prove of much value to the metallurgical world.

The author could detail all the tests which he has made to show the movements of the pointers at every few moments, but as what he has given is in a practical sense all that is necessary to prove the theory advanced by this paper, such minute details have been omitted. Suffice it to say that the principles in expansion, contraction and stretching presented are not deduced from one or two experiments, but from a

large number of tests, and that with a weight of 500 pounds suspended at E and an iron of about 1.50 in silicon, .050 sulphur, he has made a difference of one-quarter inch in the final contraction of the free and restrained bars, and is of the opinion that with higher silicon or a softer iron he will be able to make the final stretching of the restrained bar to exceed that of the free one over three-eighths of an inch. The size of pattern A is one inch by one and one-half inch, and three feet four inches long over all, as shown by the cut at A, Fig. 78, page 426.

Returning to the subject of stretching cast iron, the author will cite a few instances in every-day heavy founding that will assist further to demonstrate the existence of such a quality. As one illustration of this fact, I refer to the making of some large Martin pump castings with my own hands about 1879 at the Cleveland Rolling Mill Company's foundry, in Cleveland.

These were of a design requiring many large cores, and when the patterns were made the usual stereotyped contraction of one-eighth inch per foot was allowed for the castings. I had made about four of these castings when I was one day pounced upon by the manager who wanted to know what I had done to cause the castings (cope as well as nowel parts) to be larger than the patterns, which had caused a great loss in other smaller castings that would have to be made over in order to correspond in size to the different parts of the large pump casting. The investigation simply resulted in showing that the designer, draftsman and pattern-maker were all ignorant of the qualities which exist in cast iron, permitting it to be stretched when cooling, after solidification has taken place.

It is natural to inquire as to the reason for the iron being stretched to such a large degree in these castings. The author's hypothesis is that owing to the castings being filled with large cores containing both slim and thick cast and wrought core rods, as soon as the cores became heated they and all the rods expanded and, by outward pressure which they exerted, overcame the resistance of the outer body of the green sand mould; and while the metal was in a fluid state, instead of shrinking, as is generally the case with heavy castings, some of it would actually flow back and run out over the flow-off gates. This action continued until solidification took place; then stretching of the half molten and "frozen iron" came into play, expanding all sides of the green sand mould until the force of the expanding cores and their rods gave way to that of the outer mould's body of metal, and the casting attained that point of cooling, as shown in the experiments illustrated with the author's device, Fig. 77, in which it had cooled sufficiently to overcome the influence of the power most greatly exerted to stretch the iron, thereby exerting an expanding power at a time when the cooling iron was most susceptible to stretching, which, of course, varies according to the thickness of a casting, its rate of cooling, etc., to obtain a temperature from 1,600 degrees F. down to 1,200 degrees F., as cited on page 427, in the stretching tests with the apparatus above described.

The case of the pump which has been cited exhibits a form of power, proper to be classed as expansion and compression resistance to contraction. We still have another form, which I will call heat resistance, and which displays its power to stretch iron by reason

of the carbon being more completely transformed to graphite under slow cooling. An example of this is an experiment which was made by a New York City founder some years ago.

The feat achieved by the founder was that of casting a balance wheel of about 18 inches diameter, having a rim about two inches thick, with four to six arms only about one-quarter inch thick. The wheel was on exhibition for some time and the wonder of founders was how it held together. The author was informed that the secret lay in a heating device, so arranged as to keep the arms at a high temperature and to preserve the temperature close to that of the rim, as the latter was cooled off. The author would say that the feat was not achieved wholly by reason of extended heat, evolving greater graphite carbon in the arms. The element of stretching also assisted while keeping the arms hot, thus permitting the pulling power of the rim to extend them.

When we consider the difference that naturally exists in the contraction of light and heavy bodies, so clearly displayed in the test cited, pages 405 and 421, of a four by nine and one-half by two bar, it cannot but be evident that had the above wheel been left to cool off naturally, the arms would have pulled away from the rim. This founder's achievement involves a lesson not to be forgotten by any interested in the founding or designing of machinery.

The ignorance which prevails on the question of contraction in cast iron is astonishing. It is only the fact that cast iron will stretch that saves many from having their ignorance on this subject exposed. There are many castings made that would not hold to-

gether were it not for the stretching property of cast iron. In this case, as in all else in mechanics, there is a limit to abuse, and it is not infrequent that we find this limit passed; but when it is, the poor founder is almost invariably held responsible for the results. When the casting cracks, the designer is the last man upon whom there is any suspicion of blame, when in reality he often is the one at fault.

This is not to be taken as relieving the founder of all responsibility in the question of cracked castings, etc. When the principles involved in the stretching and contraction of cast iron are understood, he can often, by methods of cooling and permitting freedom for contraction, do much to partly relieve disproportionate castings of internal strains, which, if they do not rupture a casting before it leaves the founder's door, may often do so after it has gone into use. It must be remembered that there is hardly a piece of machinery but has some part stretched, or held in strain, and if the latter is the case, we often can have fear of fracture or cracks, eventually causing injury of property and loss of life.

CHAPTER LVI.

UTILITY OF CHILL TESTS AND PRINCIPLES INVOLVED.

Many possess false ideas as to the utility of chill tests. Some believe that if a founder knew what an iron would "chill" in some test bars or block chills, they should be able to define what depth of chill any casting would have, no other qualities being known than that of the iron used and form of the casting.

There are numerous elements which affect the depth of chill in a casting, other than the chilling qualities of the iron used, which make it impracticable to say just what the depth of chill in a casting will be, from the depth of chill in a test bar or block. All we can do with a test bar or chill block is to get a relative knowledge of the natural chilling qualities of an iron. To illustrate this, I will now state some principles:

First. Any casting will show a deeper chilling by remaining in contact with its chill until all the metal in the casting has solidified or it becomes cold, than if the union of the casting or chill were broken before it had occurred.

Second. A hot-poured iron will remain longer in contact with a chill than a dull-poured iron, for as soon as the molten metal has solidified it commences to contract, and hence it must be plain to any one that the same grade of iron, if pulled away more

quickly from a chill at one time than another, will give a different thickness of chill.

Third. The least difference in the grade of an iron causes a variation in its contraction, thereby causing one quality of iron to pull away from a side chill more than another.

Fourth. The thickness of chill used affects the depth of the chilling in the casting, up to the limit of the chill being affected, in suddenly extracting heat to counteract the carbon at the surface body of a casting being evolved into any graphitic carbon.

Fifth. The thickness of a casting affects the depth of a chill.

Sixth. Degrees of fluidity affect chilling. A hot-poured iron will chill deeper than a dull one. See page 388.

It is shown by the above that certain conditions have an effect in regulating the depth of a chill in castings, and that it is impossible for any one to tell what the exact "chill" will be in a casting by means of a chill test; but where one has had considerable experience with the special casting and takes into consideration all the elements in the case, he can closely draw his own deductions as to what depth of chill he may expect in the castings. To do this we must specially consider the thickness of our casting in connection with the iron used, also whether the casting is one to remain in contact with its chill mould, or pull away from it; also the fluidity of the metal with which a casting is poured. Further information on chilling is found on pages 323, 489 and 500.

CHAPTER LVII.

UTILITY OF TRANSVERSE, CRUSHING, IMPACT AND SHOCK TESTS.

The tests called for in our engineering and other scientific test books include transverse, tensile and crushing strength, a few giving impact. Of all these, none can surpass in value in a general way the transverse test, with its accompaniment of "deflection" for foundry practice, simply because castings are chiefly subjected to such strains. The utility of tensile tests will be found discussed on page 439. The quality of cast iron to withstand crushing loads is also one often of much importance to the engineer and founder. The values found by the author from which the relation between crushing and tensile strength may be deduced lead him to affirm that the elements constituting a test in transverse, deflection and chill are for general purposes, largely a good index as to the crushing strength. An iron having a high transverse strength combined with small deflection should prove the best to withstand crushing loads.

Impact tests on the side of test bars are of no practical value in assisting to determine what castings can withstand shocks or blows. If there is any form of tests with test bars, to demonstrate the power of iron to withstand shocks or blows, there is much more

practical sense exhibited in looking to high transverse and deflection combined with a low contraction, than to impact blows on the side of a test bar. A practical way to apply an impact test is to the castings themselves. The car wheel men teach a lesson in this respect. Here we find the inspector selects from a large stock one wheel out of every hundred, and if by dropping a 140-pound weight on the hubs of the sample wheels from a height of 12 feet the sample wheels stand five blows each, all the other wheels are then accepted. We make no attempt to describe the details of these tests. We only outline the general plan to illustrate the absurdity of thinking to be guided by impact blows on the side of test bars.

The power of castings to withstand shocks or blows is often far more affected by their proportion or design than by the quality of iron composing them. There is altogether too much indifference exhibited by designers of machinery to proportioning castings so as to have the least possible internal contraction strain in them. Some designers seem to ignore wholly the fact that a light body will contract more than a heavy one. Many castings have been made, the iron in which would test all right as far as test bars were concerned, but subjecting them to shocks or blows, would imply that the iron was not of the right character. This again illustrates the impracticability of impact tests on test bars and shows that a weak, high-contraction iron can often be of much more value in a well-proportioned casting than the reverse kind of iron in an ill-proportioned one.

A. E. Outerbridge's shock tests form an interesting study in this connection. In these tests, Mr. Outer-

bridge found that shocks or light blows delivered on test bars increased their strength, and therefore illustrate the benefits to be derived by the gradual increase of severity in shocks to strengthen castings, such as guns which are subjected to great strains from sudden jars or blows to the metal comprising their bodies. They also show wherein many castings long in use can have their durability increased, becoming really better than new castings.

These tests were made by means of twelve companion test bars that had been moulded in one flask and cast with the same gate and ladle of iron. Six of these bars would be subjected to shocks by reason of tumbling in a "tumbling barrel," and in other cases the shocks would be transmitted to the bars by means of tapping the test bars on their end with a hand hammer. The six bars not receiving shocks in any manner were invariably found the weakest. The bars receiving the shocks were shown by a thousand and more tests made by Mr. Outerbridge to have been increased in strength from ten to fifteen per cent. and the largest gain, in a few instances, was found to be about 19 per cent. The bars tested were one and one-eighth inch round, and also square bars of one inch section, both fifteen inches long. Mr. Outerbridge says the crucial test was in subjecting six bars to 3,000 taps each with a hand hammer upon one end only of each bar. The tumbling barrel process of giving shocks to bars continued for about four hours. The publication of Mr. Outerbridge's discoveries by trade papers has led many founders to experiment in testing his deductions, and all have found them to be true, some even exceeding the strength obtained by Mr. Outerbridge.

One case which has come to the writer's knowledge showed a gain of 29 per cent. by reason of tumbling test bars. For results with chilled bars, see page 527.

Mr. Outerbridge was led to demonstrate that shocks could increase the strength of cast iron by first observing that chilled car wheels rarely cracked in ordinary service, after having been used for a considerable length of time. He says if they did not crack when comparatively new, they usually lasted until worn out or condemned for other causes. Mr. Outerbridge found that, up to the point of the shock relieving the internal strains by permitting the individual metallic particles to re-arrange themselves and assume a new condition of molecular equilibrium, any further shock did not increase the strength. He does not say this would injure it, and, in speaking of a few practical deductions for universal application to be drawn from his tests and observation, he says: "Castings such as hammer frames, housings for rolls, cast iron mortars or guns which are to be subjected to severe blows or strains in actual use, should never be tested to anything approaching the severity of intended service." Mr. Outerbridge's discovery is a valuable one, and can find practical application in many ways, especially in showing the light-work founder that "tumbling" castings is beneficial; but that it is best, when practical, where there are any fears of castings being broken, to start slowly and gradually increase the speed to the limit generally practiced when "tumbling."*

* The paper giving all his tests, etc., was originally presented at the meeting of the American Institute of Mining Engineers, in Pittsburg, Pa., February, 1896, and can be found in its proceedings of that year.

CHAPTER LVIII.

ACHIEVING UNIFORM RECORDS, AND UTILITY OF TENSILE TESTS.

Any research to discover uniformity between tensile and transverse tests of the past is labor lost. One form has recorded the iron to be weaker or stronger than the other, and only bewilders instead of assuring an investigator that he has obtained any knowledge of the iron's true strength. There is no reason why the same iron should show such erratic records as have been evinced in the past, between tensile and transverse tests, that can be charged to the iron proper.

When evils due to casting test bars flat are considered as proven in Chapter LXV., the greatest cause for the wide difference recorded in the past is clearly displayed. How is it possible to expect other than erratic and unreliable records, when the fact of a flat-cast one-inch-area test bar being 200 to 400 pounds stronger on one side than the other is considered? Any one giving thought to this subject cannot but condemn the unreliable records which casting flat must cause, and become convinced that the plan of casting on end far surpasses past methods, in order to insure uniformity between tensile and transverse or either tests taken from bars cast off from the same ladle.

For foundry and engineering purposes it can be said that tensile tests are often valuable for comparative

tests. With a standard length of a bar for transverse strength and one of equal area for tensile testing of the round form and cast by the system advocated by the author in Chapter LXVII., his study on comparisons leads him to say that transverse and tensile tests will be found to bear a very close relation to each other. With round test bars from both transverse and tensile tests, the author is confident that future statistics will demonstrate that the latter test may, for some purposes, be of as much benefit for a comparative test as are transverse tests. One difficulty in obtaining tensile strength often lies in the method of obtaining them. Some machines can take such a rigid grip as to exert a strain on some portion of the specimen, instead of permitting the test bar to adjust itself centrally so as to insure a uniform pull over its entire breaking area. Cast iron, being a very rigid metal, requires different treatment in insuring a uniform pull than steel or wrought iron, but with care on this point, or the use of specially designed test bars often arranged to permit a good area for gripping, or having shoulders cast on each end with holes in them at cross angles to each end whereby pins can be inserted to allow a specimen to adjust itself centrally to its load, very accurate tests may be obtained. Tensile, like transverse, tests can be but comparative (see Chapter LXIX.), to learn of the strength of cast iron, and for this purpose can often be well utilized.

CHAPTER LIX.

CONTRACTION vs. STRENGTH OF CAST IRON.*

As indicating the unfitness of a test bar to record contraction of cast iron, when it has been proven of no value to record strength, experiments which the author has lately conducted have demonstrated that the percentage of combined or graphitic carbon in a light casting or small test bar can often be regulated as much by varying conditions in the physical qualities of the mould as by varying percentages in the elements of sulphur, silicon, manganese, phosphorus, etc., generally contained in foundry pig metal. We will first consider the physical qualities which can affect the strength of an iron, according to the size of a casting or test bar, and which is chiefly (aside from the "iron") dependent upon the nature of the carbon, whether it is in the combined or graphitic form. See page 306.

Believing from the results of previous experiments and every-day experience that if the corners and the central portion of square test bars were analyzed, a difference would be found to exist in their percentage of combined or graphitic carbon; also that the combined carbon would be less in a one-inch square bar than in a one-half-inch square bar, both poured from the

* Extract from a paper read before the Foundrymen's Association, Philadelphia, Pa., September 4, 1895.

same iron and gate, I forwarded the specimens of which the analyses are herewith given to Charles A. Bauer, M. E., general manager of Warder, Bushnell & Glessner Co., Springfield, O., who had his son, Charles L. Bauer, a chemist, make the determinations shown in the following paragraphs:

The specimens were one-half inch square, one inch square and one and one-eighth inch round bars, belonging respectively to light machinery and chill roll iron tests, which were among those reported in my paper before the Western Foundrymen's Association, October 18, 1894, seen on page 450; paragraph No. 1 giving the combined carbon at the corners and center surface of the fracture of the one-inch square bars in the chill roll and light machinery mixtures.

Paragraph No. 2 is a report of the sulphur contents of the center of the bars shown in paragraph 1 and also that of the one-half inch square and one and one-eighth inch round bars shown in paragraph 3, which were poured with the same gate and iron as those in paragraph 1.

Paragraph No. 3 shows the difference in combined carbon existing in the center of the one-half inch square, one inch square and one and one-eighth inch round bars described in paragraphs Nos. 1 and 2.

DETERMINATION No. 1.—Combined carbon in chill roll iron: At the corners, 1.55 per cent., at the center of the fracture, 1.416 per cent., or .134 per cent. more combined carbon in the corners than in the middle of the test bars. In light machinery iron: At the corners, .72 per cent.; at the center, .65 per cent.; or .07 per cent. more combined carbon in the corners than in the center of the fracture.

DETERMINATION No. 2.—Sulphur in chill roll iron: At the center of fracture in one-half inch square, .046 per cent.; one inch square, .044 per cent.; one and one-eighth inch round, .046 per cent. In light machinery iron: At the center of fracture in one-half inch square bar, .0819 per cent.; one inch square, .079 per cent.; one and one-eighth round, .0825 per cent. Mr. Bauer writes that the difference in sulphur at the center and the corners of the different bars is not perceptible.

DETERMINATION No. 3.—Combined carbon in chill roll iron: In one-half inch square, 2.700 per cent.; one inch square, 1.416 per cent.; one and one-eighth inch round, 1.250 per cent. Difference in the extreme of the combined carbon in the one-half inch square and one and one-eighth inch round bar, 1.450 per cent. In light machinery iron: In one-half inch square, .854 per cent.; one-inch square, .650 per cent.; one and one-eighth inch round, .704 per cent. Difference in extremes, .204 per cent. of the combined carbon in the one-half inch and one and one-eighth inch round test bars at their center of fracture. The silicon in the light machinery is 1.83 per cent.; in the chill roll, .71 per cent.

The percentage of combined carbon and "iron" in a casting or test bar controls the strength of the iron and also its contraction. The percentages of sulphur, silicon, manganese and phosphorus in cast iron are but factors in connection with the time it takes a test bar or casting to solidify and become cold, determining the degree to which the carbon takes the combined form.

The above exhibits plainly prove that a slight difference in the fluidity of metal, or dampness in the

"temper" of sands, as commonly used in ordinary foundry practice, can cause a radical difference in the percentage of combined carbon, in the same size and form of small castings or test bars from the same mixture of iron, poured out of the same ladle. The determinations Nos. 1, 2 and 3 also indicate necessity of adopting for physical tests the size and form of test bar least liable to irregularities in the combined carbon composing its shell or outer body, to be caused by varying conditions in the "temper" of sands and fluidity of metals, etc.

As degrees in the strength of iron can be affected by the "temper" of sand and fluidity of metal at the moment it is poured, so can contraction records be likewise affected, making them deceptive. Experiments which I have conducted to discover if the same conditions which give erratic results in strength records would not do likewise in contraction, have only the more confirmed me in the advocacy of a round bar cast on end, wherever one desires to be wholly or partially guided by physical tests.

To learn whether differences in the mould could cause changes in the length of contraction in small bars of the same size, cast in the same mould with the same iron, out of the same ladle and at the same moment, I took three patterns one-half inch square, 12 inches long, and cast two of them between yokes and a third bar in a divided chill to form two sides and bottom of the mould, the fourth side being formed by the sand of the cope. The two bars cast between yokes had drier sand for one than for the other. The dampest sand was not so damp but that a sound casting would be produced and the two sands differed no more than can

often be found between the "temper" of sands in one shop. All three bars were placed equidistant in the mould and gated by means of two upright "sprues" which led down to a runner in the cope extending over the three bars in the center, insuring the filling of the three moulds at the same time with the same hand ladle of iron. The test bars formed in the chill and dampest sand would show a greater contraction than the one enclosed in the driest sand. I have conducted quite a number of these tests and always found them in the same line, those cast in the chill showing the greater contraction. In several cases, the extremes of one flask gave a full one-sixteenth inch difference in the contraction of the three bars. In the extremes between the "temper" of the wetter and drier sand, I have found a difference of fully one thirty-second part of an inch to exist in the contraction of two one-half inch bars poured from the same hand ladle at the same moment, thereby proving that a test bar as small as one-half inch square or round is altogether too sensitive to variation in the "temper" of moulding sand to be relied upon to afford any true knowledge of the natural contraction of an iron.

To discover what effect, if any, degrees in dampness or "temper" of sand have on a round bar cast on end, I took a pattern one and one-eighth inch in diameter and made a dry sand mould, using a piece of six-inch gas pipe to mould it in, leaving both ends open. After this little mould was dried in an oven, it was set on end upon a planed plate and the distance equally divided between two empty gas pipes. Each of these two latter pipes was then rammed up with "green sand" of a different temper. Each test bar

had a projection cast on the upper end exactly two feet from the bottom of the mould, which was formed by the bottom plate to measure contraction by. The three bars were poured by one runner in the center of the three moulds, the iron dropping from the top. I made these three bars two feet long, so as to give a greater length than was in the one foot one-half inch square bars, to better detect any difference that might exist in the contraction of the bars due to variation in the "temper" of the sand. On these bars being measured, no difference could be found in their contraction—a further proof of the necessity of using a bar larger than one-half inch square or round to show the real contraction of an iron.

I also made tests with one and one-eighth inch round bars cast flat, but did not find that the radical variation which existed in the "temper" of the sand made any difference in the length of their contraction. Previous to these tests, I also made some in our foundry in the presence of E. Duque Estrada, M. E., of Pittsburg, a member of the American Society of Mechanical Engineers' Testing Committee, to learn whether degrees in fluidity of iron would affect the contraction of large-sized test bars or thick castings. To test this point, two bars two inches square and forty-eight inches long were moulded together in the same mould. One was poured with the metal as "hot" as it could be obtained from the cupola, and the other with the same ladle cooled down to have the metal as "dull" as possible and still obtain a full-run bar. Two sets of these experiments were made, but no difference was found in their contraction. The fact of there being no visible difference in the con-

traction of the two-inch square bars cast flat, also the one and one-eighth inch round bar cast flat and on end, was due to the body of the test bars being sufficiently massive to overcome any tendency which variations in the fluidity of metal or dampness of the sand could exert in causing a difference in the combined carbon.

With large-sized test bars cast on end, possessing no corners to be affected by the "temper" of sands and fluidity of metal, contrary to the conditions seen in a square test bar, we are justified in placing the utmost confidence in the record which they may present. And were it not that in accepting castings there is generally a large leeway permitted the founder, regarding the physical properties of the iron in his castings, the error of using bars as small as one-half inch square or below one inch area would have been clearly demonstrated long ere this.

CHAPTER LX.

COMPARISONS OF STRENGTH IN SPECIALTY MIXTURES.*

This chapter is a revised extract from a report of the author's labors as a member of the Western Foundrymen's Association Testing Committee, and presents a series taken from about one hundred tests on the strength of cast iron mixtures such as are used for gun metal, chill rolls, car wheels, heavy machinery, light machinery, stove plates and sash weights, a list which can be seen to cover very nearly all mixtures or "grades" necessary to cast iron founding.

Each founder in casting a set of these test bars from the patterns which the author furnished made three one-half inch square, three one inch square, three one and one-eighth inch in the rough, and three one and one-eighth inch turned. These one and one-eighth inch round bars in the rough and turned are of an area as nearly equal to one square inch as it is practical to make them. The turned bars were cast with a swell on so as to measure about one and five-eighth inches in diameter for about four inches of their length in the center. This swell was turned down until the bars measured close to the size of their companion, one and one-eighth rough bars. The comparison between

* Read at the meeting of the Western Foundrymen's Association, at Chicago, Wednesday evening, Oct. 24, 1894.

the rough round and the turned bar enables us to perceive the difference that may exist between the strength of the iron with its surface affected by the walls of a green sand mould and that of iron having its rough surface turned off.

It was first planned to have all these test bars cast on end, so as to afford the most favorable conditions to insure solid bars, etc., but in starting with car wheel mixtures, difficulty was found in getting the half-inch square test bars to "run," and as there were other strong irons I desired tests from, I had, on account of the one-half bars, to change the plan of casting and had all bars cast flat. The three test bars from each of the four sizes were cast all in one flask, poured from the same gate, and out of the same ladle.

These test bars were cast by some of the most prominent foundry specialists in this country. They are not a crucible melt of estimated mixtures or of a special heat, but are taken from "regular heats" "run" for making castings in the specialties herein mentioned, therefore represent the strength of the actual metal used in actual practice for the manufacture of the castings outlined as far as is practical with bars cast flat. A complete chemical analysis of the various mixtures obtained in the tests shown in this Chapter can be seen on page 320. The analyses were all taken from the rough bars shown in the respective Tables.

The micrometer measurements given in the following tables are the average of dimensions taken from the four sides of the square and round bars and hence give the size of the test specimen in the thousandth part of an inch. The common rule measurements means the size as closely as it is practical to roughly

state the dimensions. All the bars were cast 15 inches long and in breaking them for transverse strength they rested on pointed supports, 12 inches centers. The last two columns in the Tables give the strength per square inch. The outside column is used only for the half-inch square bars, so as to illustrate two methods of figuring, and is obtained by multiplying the breaking load by eight, a method advanced by some, for one-half-inch bars. The inner is obtained by the rules shown in Chapter LXI., page 463. The area of a bar 1.1284 inch in diameter is equal to the area of one inch square; by keeping this in mind the figures in the micrometer columns can have their relation to a square inch readily defined.

TABLE 44.—TRANSVERSE TESTS OF GUN METAL.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.	
	Rough bars.					
1	½ in. square.........	.491 in.	.120 in.	376	1,560	3,008
2	" "	.501 "	.115 "	420	1,673	3,360
	Planed bars.					
3	½ in. square.........	.491 in.	.250 in.	384	1,593	3,072
4	" "	.495 "	.270 "	360	1,469	2,880
5	" "	.494 "	.200 "	316	1,295	2,582
	Rough bars.					
6	1 in. square...........	1.002 in.	.090 in.	3,500	3,486	......
7	" "	996 "	.085 "	3,380	3,400	......
8	" "	1 044 "	.095 "	3,428	3,145	......
	Planed bars.					
9	1 in. square...........	1.007 in.	.130 in.	3,140	3,096	......
10	" "	1.005 "	.120 "	3,095	3,064	......
11	" "	1.005 "	.110 "	3,072	3,042	......
	Rough bar.					
12	1⅛ in. diam...........	1.132 in.	.125 in.	3,708	3,686	......
	Turned bar.					
13	1⅛ in. diam.	1.139 in.	.150 in.	3,320	3,258	......

Test bars, Table 44, were furnished by Builders' Iron Foundry, Providence, R. I. Tested by Thomas D. West, at the works of the T. D. West Foundry Co., Sharpsville, Pa., Sept. 18th, 1894. Witnesses, Geo. H. Boyd and G. M. McIlvain.

The first series of tests we will present is that recording the strongest mixture, seen in Table 44; the

second, the next best in strength, and so on, the last Table being the weakest iron.

The test of the gun metal, Table 44, page 450, showed the planed bars of a very coarse grain partaking of a fibrous nature, somewhat after a good grade of wrought iron, having a fracture of a dark color. The metal of the rough bars showed the fracture in the one-half-inch square bar to be strictly white and in the one-inch square test bars to be of a crystalline mottled nature, and in the rough one and one-eighth inch

TABLE 45.—TRANSVERSE TESTS OF CHILL ROLL IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
14	½ in. square.........	.509 in.	.120 in.	230	888 1,840
15	" "	.518 "	.150 "	300	1,119 2,400
	Rough bar.				
16	1 in. square.....	1.032 in.	.120 in.	2,590	2,432 ......
	Rough bar.				
17	1⅛ in. diam.........	1.140 in	.150 in.	3,040	2,980 ......
	Turned bar.				
18	1⅛ in. diam...........	1.124 in.	.190 in.	3,020	3,044 ......

Test bars furnished by Lewis Foundry & Machine Co., Pittsburg, Pa. Tested at the works of McConway & Torley, Pittsburg, Pa., June 27th, 1894, by J. B. Nau, Allegheny, Pa. Witnessed by R. G. G. Moldenke, E. M., Ph. D.

diameter bars of a similar character, but to a little less degree than shown in the one-inch square bars. The large open-grained bars, or those of numbers 3, 4, 5, 9, 10 and 11, illustrated in Table 44, were planed from the muzzle disc of a 12-inch mortar casting, and bars 1, 2, 6, 7, 8, 12 and 13 were cast with metal which was used to pour a lower base ring for a 12-inch spring return mortar carriage. The charge of iron for the mortar was very much harder than that used for the base ring, but as it was cast in a very

large mass and cooled very slowly it is not surprising that the fracture shows the iron in the mortar body to be much softer (or open-grained) than that in the test bars from the base ring. The tensile strength of the two specimens taken for acceptance of the 12-inch return mortar or lower base casting as above described was as follows:

No. 1 . . . 37,100 lbs. No. 2 . . . 37,000 lbs.

TABLE 46.—TRANSVERSE TESTS OF CAR-WHEEL IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars				
19	½ in. square.........	.474 in.	.090 in.	273	1,213 2,184
20	" "	.496 "	.090 "	280	1,138 2,240
21	" "	.491 "	.090 "	278	1,1[illegible]8 2,224
	Rough bars.				
22	1 in. square..........	1.012 in.	.075 in.	2,535	2,476 ......
23	" "	1.022 "	.074 "	2,415	2,313 ......
24	" "	1.007 "	.075 "	2,294	2,262 ......
	Rough bars.				
25	1⅛ in. diam.	1.090 in.	.111 in.	2,340	2,508 ......
26	" "	1.072 "	.100 "	2,360	2,615 ......
27	" "	1.135 "	.100 "	2,568	2,538 ......
	Turned bar.				
28	1⅛ in. diam..........	1.174 in.	.170 in.	3,050	2,819 ......

Test bars furnished by A. Whitney & Sons, Philadelphia, Pa. Tested by John R. Matlock, Jr., at the works of Riehle Bros.' Testing Machine Co., Philadelphia, Pa., June 27th, 1894. Witness, W. C. Cutler.

In the chill roll iron, Table 45, page 451, a few of the pieces were selected after having been broken for transverse strength and pulled for the tensile strength. Bar No. 15 pulled 6,100 pounds; No. 16 pulled 23,700 pounds; and No. 17 pulled 30,100 pounds. The iron in the half-inch bars showed a white crystalline fracture, likewise the one-inch square. The one and one-eighth inch diameter rough bars showed a very close knit grain tending to a light color. The one and one-eighth inch turned bars are also very close

grained, a little darker in color than the one and one-eighth inch bars, but both of the latter exhibit to an expert the appearance of great strength as being of exceptionally strong metal.

The iron in the car wheel, Table 46, page 452, shows the half-inch bars to be white and crystalline. In the one-inch square bar the iron is mottled, tending to white. In the one and one-eighth inch round rough bars the metal is more evenly mottled and less white than in the one-inch square. The one and one-eighth inch round turned bars show a very rich dark gray color. Bar No. 26 pulled tensile 23,270. This mixture proved to be an excellent iron.

TABLE 47.—TRANSVERSE TESTS OF HEAVY MACHINERY IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.
	Rough bars.				
29	½ in. square.........	.504 in.	.195 in.	380	1,496 3,040
30	" "	.503 "	.220 "	432	1,707 3 456
31	" "	.504 "	.185 "	372	1,465 2 976
	Rough bars.				
32	1 in. square.........	1 004 in.	.100 in.	2,464	2,444 ......
33	" "	1.009 "	.090 "	2,510	2,465 ......
34	" "	1.007 "	.100 "	2,640	2,604 ......
	Rough bars.				
35	1⅛ in. diam.........	1.137 in.	.100 in.	2,786	2,745 ......
36	" "	1.135 "	.120 "	2,824	2,791 ......
37	" "	1.143 "	.100 "	2,500	2,437 ......
	Turned bars.				
38	1⅛ in. diam.........	1.125 in.	.120 in.	2,257	2,271 ......
39	" "	1.125 "	.150 "	2,488	2,503 ......
40	" "	1.124 "	.140 "	2,344	2,363 ......

Test bars furnished by the Walker Manufacturing Company, of Cleveland, Ohio. Tested by Thomas D. West, at the T. D. West Foundry Co., Sept. 18th, 1894. Witnesses, Geo. H. Boyd and G. M. McIlvain.

The iron in the above half-inch test bars presents a very close, compact grain, tending to white. The one-inch square bars show a close, dense fracture, tending to a light gray color. The one and one-eighth inch round

bars are less dense and present more of a dark gray color than the one-inch square bars. The turned bars show a fine, rich-colored, compact iron, such as would stand exceptional wear and resistance to fracture. Bar No. 34 pulled 26,160 pounds, and No. 35, 28,676 pounds. For medium to heavy machinery, this metal should make a most serviceable casting.

TABLE 48.—TRANSVERSE TESTS OF LIGHT MACHINERY IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.	
	Rough bar.					
41	½ in. square.........	.499 in.	.200 in.	454	1,823	3,632
	Rough bars.					
42	1 in. square...........	1.016 in.	.130 in.	1,710	1,657	......
43	" "	1.021 "	.125 "	1,760	1,688	......
44	" "	1.008 "	.115 "	1,800	1,771	......
	Rough bars.					
45	1⅛ in. diam..........	1.146 in.	.160 in.	1,795	1,741	......
46	" "	1.156 "	.180 "	2,220	2,115	......
47	" "	1.141 "	.180 "	1,980	1,938	......
	Turned bars.					
48	1⅛ in. diam..........	1.162 in.	.200 in.	1,705	1,609	......
49	" "	1.160 "	.210 "	1,720	1,628	......
50	" "	1.175 "	.210 "	1,775	1,637	......

Test bars furnished by Taylor, Wilson & Co., Ltd., Allegheny, Pa. Tested by J. B. Nau, at the works of McConway & Torley, June 19th, 1894. Witness, R. G. G. Moldenke, E. M., Ph. D.

The fracture of above set of tests shows an exceptionally good iron for light work. The tests record above the average for soft iron as regards strength. The color is a rich gray, devoid of that silver look many castings display that are desired to be of a soft quality. The half-inch bars are the closest grained, the one-inch square the next in order, then comes the one and one-eighth inch in the rough, followed by the turned one and one-eighth inch bars, which are the most open-grained, rich in color and graphite. A few of these bars were pulled for the tensile strength.

No. 41 stood 6,000 pounds; No. 43 stood a pull of 19,000 pounds, and No. 47 separated at 21,120 pounds.

TABLE 49.—TRANSVERSE TESTS OF STOVE PLATE IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.	
	Rough bars.					
51	½ in. square.........	.475 in.	.220 in.	160	711	1,280
52	" "	.476 "	.260 "	170	747	1,360
53	" "	.474 "	.250 "	150	669	1,200
	Rough bars.					
54	1 in. square...........	.994 in.	.150 in.	1,757	1,778	......
55	" "	.975 "	.160 "	1,660	1,747	......
	Rough bars.					
56	1⅛ in. diam.	1.118 in.	.170 in.	1,780	1,813	......
57	" "	1.126 "	.170 "	1,775	1,783	......
	Turned bars.					
58	1⅛ in. diam...........	1.127 in.	.180 in.	1,320	1,322	......
59	" "	1.140 "	.180 "	1,440	1,412	......
60	" "	1.125 "	.180 "	1,335	1,343	......

Test bars furnished by Bissell & Co., Allegheny, Pa. Tested by J. B. Nau, at the works of McConway & Torley, June 20th, 1894. Witness, R. G. G. Meldenke, E. M., Ph. D.

The above tests of the inch square and round bars assert this iron to be of good strength for the work intended. A factor in this series which will no doubt attract attention is the light load the half-inch bar stood in comparison with the larger sizes and only goes to further demonstrate the erratic and deceptive results which we may expect with small test bars. No. 53 stood 6,000 pounds tensile; No. 54 stood 16,600 pounds; and No. 60 stood 17,150 pounds.

In studying Table 50, one is impressed with the uniformity of the load the bars stood and also the weight necessary to break them, for as a general thing "white iron" exhibits little strength in castings. The tests would lead us to decide that the greatest weakening element in castings made of "white iron" is due to excessive contraction, which is characteristic of

TABLE 50.—TRANSVERSE TESTS OF SASH WEIGHT OR WHITE IRON.

No. Test.	Common rule measurement.	Microm't'r measurement.	Deflection.	Broke at in pounds.	Strength per square inch in pounds.	
	Rough bars.					
61	⅝ in. square.........	.488 in.	.062 in.	175	735	1,400
62	" "	.484 "	.060 "	160	683	1,280
63	" "	.487 "	.062 "	170	717	1,360
	Rough bars.					
64	1 in. square..........	.992 in.	.070 in.	1,340	1,361	......
65	" "	.994 "	.040 "	1,325	1,341	......
66	" "	.992 "	.055 "	1,365	1,386	......
	Rough bars.					
67	. 1⅛ in. diam.........	1.114 in.	.050 in.	1,355	1,392	......
68	" "	1.113 "	.055 "	1,440	1,480	......
69	" "	1.117 "	.050 "	1,320	1,346	......

Test bars furnished by E. E. Brown & Co., Philadelphia, Pa. Tested by W. C. Cutler, at the works of Riehle Bros.' Testing Machine Co., Philadelphia, Pa., June 29th, 1894.

"white iron." Many castings made of white iron have been known to fly to pieces from internal contraction strains when cooling, without a jar or the least weight being placed upon them. The reason for not showing any turned bars in this test is due to the difficulty or rather the impracticability of machining such a hard metal. Bar No. 69 pulled 7,125 pounds. The fracture of all the bars is of a very pronounced crystalline white appearance, as can be seen in Fig. 62 on page 275.

TABLE 51.—SUMMARY OF THE STRONGEST TESTS.

No. of bar.	Transverse Strength per square inch.	No. of bar.	Tensile Strength per square inch.	Specialties of mixtures.
12	3,686	...	*37,100	Gun Metal.
17	2,980	17	30,100	Chill roll.
26	2,615	26	23,270	Car wheel.
36	2,791	35	28,676	Heavy machinery.
46	2,115	47	21,120	Light machinery.
56	1,813	60	17,150	Stove plate.
68	1,480	69	7,125	Sash weight.

*This tensile test is No. 1 of Mr. R. A. Robertson's gun metal report.

Having completed the record of tests, it is now in order to learn what they prove. It will require but little study of the Tables to find that the small bars do not record any true variation in degrees of strength, no matter what quality of iron is used. It asserts that gun metal, chill roll, car wheel and heavy machinery are no stronger than light machinery or soft grades of irons. Any one experienced in the handling or use of cast iron knows that the first four qualities of iron are stronger and have a higher commercial value for strength than the fifth one.

To further illustrate the impracticability of using bars below one square inch area, we show an average of the strength of the one-half inch square and one and one-eighth inch round rough bars of all such tests given in this Chapter in the following Table 52:

TABLE 52—STRONG IRONS.

Average of ½ in. square bars.		Average of 1⅛ in. round bars.
398 pounds.	Gun metal	3,686 pounds.
265 "	Chill roll	2,980 "
277 "	Car wheel	2,553 "
393 "	Heavy machinery	2,657 "

WEAK IRONS.

Average of ½ in. square bars.		Average of 1⅛ in. round bars.
454 pounds.	Light machinery	1,931 pounds.
160 "	Stove plate	1,798 "
167 "	Sash weight	1,406 "

It cannot but be plain from the averages in Table 52 that the half-inch square bar is a size readily affected by the least change in the dampness of sands or

fluidity of metal, to afford any fair knowledge of the true relative differences in strength of cast iron. The half-inch bars from gun metal and the half-inch bars from heavy machinery practically show each to be of the same strength, where the one and one-eighth round bars indicate what we would naturally expect, namely, that the gun metal is materially stronger than the heavy machinery iron. Then again, the half-inch bars would indicate that the heavy machinery iron was very much stronger than the roll irons. The strength of the half-inch bars for light machinery, 454 pounds, indicates such iron to be stronger than gun metal, chill roll, car wheel or heavy machinery iron, while the one and one-eighth inch round bars show the light machinery to be but 1,931 pounds, as compared with 3,686 pounds for gun metal, 2,980 pounds for chill roll, 2,553 pounds for car wheel and 2,657 pounds for heavy machinery. The half-inch bars show a breaking load of 160 pounds for stove plate and 167 pounds for sash weight or "white iron," indicating that the latter is the stronger iron, while our one and one-eighth inch round bars show a strength of 1,798 pounds for stove plate, and only 1,406 pounds for sash weight iron, thus thoroughly demonstrating that one square inch area bars will fairly record the true relative degrees of strength of cast iron, whereas the half-inch square bar gives us absolutely no knowledge or indication of any difference in strength between one mixture and another, or any irons used in the different specialties of iron founding. A fact that further demonstrates the impracticability of using small test bars is that the tensile strength of the Table 51 records a uniformity in degrees of strength

closely corresponding with the transverse load of one square inch area bars in the same Table, and which would have been still better could the bars only have been cast on end.

The next size and form of a bar we come to is that of the one-inch square. In comparing the fracture of the square with those of the round bars (see pages 274 and 275), the grain of the former will average denser and all square bars, excepting those of "white iron" fracture, show the bars to be much denser at the corners than on the flat surface section of the bars, thereby giving a less uniform grain and causing more internal strains in a square bar and making it weaker than a round bar. This point the records of Table 53 fully prove, by showing that the round bars record a greater strength than square bars of like areas. I do not wish to be understood as saying we should adopt the method which will show the greatest strength in the bar, but rather the one best to insure knowledge of the natural relative qualties of cast iron mixtures, and this the round bar will do.

TABLE 53.—SUMMARY OF BEST STRENGTH AVERAGES OF ROUGH ROUND VS. SQUARE TEST BARS.

Gun metal	Average of	1⅛ in. round bars	3,686 lbs.
" "	" "	1 in. square bars	3,344 "
Chill roll	" "	1⅛ in. round bars	2,980 "
" "	" "	1 in. square bars	2,432 "
Car wheel	" "	1⅛ in. round bars	2,553 "
" "	" "	1 in. square bars	2,350 "
Heavy machinery	" "	1⅛ in. round bars	2,657 "
" "	" "	1 in square bars	2,504 "
Light machinery	" "	1⅛ in. round bars	1,931 "
" "	" "	1 in. square bars	1,705 "
Stove plate	" "	1⅛ in. round bars	1,798 "
" "	" "	1 in. square bars	1,763 "
Sash weight	" "	1⅛ in. round bars	1,406 "
" "	" "	1 in. square bars	1,362 "

This Chapter presents facts which should greatly aid in settling all disputes as to the value of the round over the square bar for recording the best natural strength of cast iron, and that we should not use a bar less than of one square inch area. The tests exhibited are all of sound fracture, and in all bars but those for sash weight iron could be machined as described on page 321. For tests of larger round bars than one and one-eighth inch diameter, and a discussion on the utility of test bars, see pages 515, 523 and 525.

Previous to this series of tests, etc., being first published, the author has no knowledge of any person thinking to advance information on the physical properties of cast iron, working other than in one "grade," and drawing conclusions from this as being applicable to anything that might come under the head of cast iron, which is a broad term and means any "grade" that the metalloids, silicon, sulphur, phosphorus and manganese when combined with metallic or "pure iron," make it workable for conversion into castings. While it is true the quality of "grades" being in cast iron was not recognized as it should be by experimenters, etc., making or reporting physical tests, the author is pleased to note that at this writing fair cognizance is being taken of this, as such course places all in a position to arrive at correct conclusions to the sooner fathom any phenomena that may puzzle or make mysterious any workings of cast iron. This latter paragraph will, of course, be noted as original with this volume, and is well to be read in connection with Chapter XXXIV., page 283.

CHAPTER LXI.

COMPUTATION OF STRENGTH PER SQUARE INCH.

The method advanced here by the author for figuring strength per square inch is to be understood as being advised for adoption only in cases where test bars are of a uniform length or resting on bearing blocks, the same distance apart (see Fig. 79, page 469), to be recognized as a standard method by any that may adopt one, two, or three square inch area bars to test the strength, deflection and contraction of cast iron, for comparative purposes.

The author has presented the rule given for the reason that it is the simplest for ordinary shop practice or general testing, and takes better cognizance of the practical elements for every-day use in a standard bar than any other formula of which he has knowledge.

Whatever systems are advanced for making relative comparisons in the transverse or tensile strength of iron, no matter what size of a bar we take, be it of one inch, two inch, or three inch areas, square or round, the author claims that none should be recognized as worthy of any serious consideration as a standard, that requires us to take into account more than one-eighth inch from the size of the test bar pattern used. The moment we attempt to figure up or down, to determine a metal's strength per square

inch or the more we are diverted from the exact size of the bar actually tested, the more we will err in drawing correct comparative deductions in any "grade" of iron. In order to obtain a relative knowledge of an iron's strength, we must confine ourselves to the use of one size of a bar (see page 521), let that be a one-inch, two-inch or three-inch square area bar, and its computation should only be permitted in taking into account any variations which may exist due to irregular work in the moulding and casting of that one size bar.

In testing bars, this effect from irregularity in moulding which can cause a variation in the size of test bars should be taken note of in compiling any records of strength filed for reference or comparison. Note should be taken of the least variations which might exist in the size of a standard test bar, as a few thousandths part of an inch in the diameter of a bar is multiplied about three times in its circumference. A little variation in the size of a test bar can make a bar considerably stronger or weaker, according as its diameter is decreased or increased from the size of the pattern from which the test bars are moulded. In compiling this work, it will be observed that the author has thought it correct to recognize this factor, and hence the adoption of the column, "Strength per square inch," seen with most of the tables given herewith.

In order that the reader may define and understand how strength per square inch was obtained for the Tables, we give two examples seen on next page, as one method is necessary for a square bar and another for a round bar:

The author could never perceive wherein the formulæ used for figuring the strength per square

inch, as advanced by our text books, etc., had any bearing on the actual area of a test bar and the load at which it broke; in fact, if to-day a founder would send the area and tests of round and square test bars to recognized authorities on mathematics to have their strength per square inch computed, the chances are that no two of them would agree, and he would be liable to wonder if present formulæ for cast iron were not rather invented for the purpose of distorting facts or making figures lie than for furnishing true data. The author has referred to this subject on several

TABLE 54.—SQUARE BAR. TEST NO. 6, PAGE 450.

Micrometer Meas.		Square.		Area of bar.
1.002 in.	x	1.002 in.	=	1.004 square inches.
Breaking load.				Area.
3,500 lbs.			÷	1.004 = 3,486 lbs. strength per sq. in.

ROUND BAR. TEST NO. 12.

Diameter.		Diameter.		Square of diameter.
1.132 in.	x	1.132 in.	=	1.281424 square inches.
Square of diam.		Decimal.		Area.
1.281424	x	.7854	=	1.006 square inches.
Breaking load.		Area.		
3,708	÷	1.006	=	3,686 lbs. strength per sq. in.

occasions since he published the methods for computation shown on this page, and is now pleased to note that at the meeting of the American Society of Mechanical Engineers, St. Louis, May, 1896, Prof. C. H. Benjamin came out openly in a letter discussing the testing of cast iron and attacked the usual formulæ for loaded beams as being incorrect, insisting that a reform should be enacted in this field of mathematics. In his letter, he expressed the opinion, as stated by the *American Machinist*, that the terms "modulus of elasticity," "elastic limit," etc., were entirely out of place as applied to cast iron, and should not be used

at all in connection with that material, and that the usually accepted formulæ for strength of beams would not hold good for cast iron beams, as had been shown by tests made by himself for the committee.

Prof. Benjamin has, no doubt, done more testing to assist experimenters and testing committees in deriving knowledge of the strength of cast iron in various forms of test bars than any other person holding the honorable position of professor of mechanical engineering in our colleges. For this reason he is certainly able and well fitted to contend for, and successfully carry through such a reform. The author trusts he will not let anything deter him from the good work he started at St. Louis, and that the movement will result, before many years, in our having some standard for computing the strength of cast iron that can be recognized as more practical and more correct than our present formulas for figuring different lengths and sizes of bars or loaded beams. It is as essential to have correctness in formulas for figuring the strength of cast iron, as it is to have correct systems for casting and testing such grades of metal. See page 517.

To any desiring to use larger bars than the one and one-eighth inch diameter shown in Table 54 and wishing to keep even figures as with a two-inch or three-inch area section, I would say that the only difference would be to have the figures 1.596 or 1.955, as the case may be, replace the 1.128, which is the diameter of a bar equal to the area of a one-inch square bar. It may be well to mention at this point that the Riehle Bros., of Philadelphia, are now also using the method for computing the strength of test bars shown in Table 54, page 463.

CHAPTER LXII.

VALUE OF MICROMETER MEASUREMENTS IN TESTING.

"What is worth doing at all, is worth doing well," is an old maxim, never better applicable than to the subject of testing. It can be readily observed that the author is an advocate of utilizing every factor that can, in any manner, assist in lessening erratic records and advance testing of cast iron to its highest perfection. Such advocacy would be inadequate did the author not argue for the adoption of the micrometer to measure the area of test bars at the point of fracture. The micrometer would be used much more than it is at the present time, did testers only more fully realize the difference a few thousandths of an inch in the diameter of a bar can make in the strength records, especially when the same are reduced to "strength per square inch."

Many would be surprised to learn how often they have been deceived in according differences in strength to records obtained simply by calipers and common rule in considering the size of bars for comparisons. If the micrometer had been used and the area reduced to "strength per square inch," as illustrated on page 462, testers would ofttimes have found bars, which were conceded by the breaking load records to be the strongest, to prove the weakest test of iron.

It is impossible to obtain rough bars of the same area. There is sure to be some difference in their sizes. It is not unusual to find one-inch area, etc., bars to be from one-sixteenth to one-eighth larger in diameter or the square than the pattern used and to find that testers make no note of such difference, but are wholly guided by the weight at which the bar broke. If one was one hundred or two hundred more than others, the highest was accepted as the strongest and best test, regardless of the bar's true area.

To illustrate how a small bar breaking with a heavier load than the large bar (each differing but a few thousandths of an inch in their area), may often, if not reduced to strength per square inch, deceive a tester 200 to 400 pounds in accepting common rule measurement and the actual load in thinking he has a true record of the iron's strength, the reader is referred to Table 44, tests Nos. 6 and 8, on page 450, showing transverse tests of gun metal. There we find two bars which, if the actual breaking loads were accepted, would deceive the tester 269 pounds, or in other words, instead of his believing he had one bar only 72 pounds stronger than the other, he actually had a difference of 269 pounds, as stated above. This should aid to clearly illustrate the importance of micrometer measurements, wherever the tester desires to truly ascertain whether any difference actually exists in the strength of his mixtures or the character of the iron produced.

Another feature well to be noticed is that of the impractibility of obtaining bars exactly round or square, or exact duplicates of their pattern. Many testers take but one measurement of a bar, while others take no measurement at all. Any following either

practice might almost as well omit their testing, for they are as liable to be misled, as be correct in their conclusions. In obtaining the area of a round or square bar, two measurements at least should be taken, multiplied together and then divided by two to obtain the average of their area to assure a tester that he has knowledge of what is closely the true total area of his bars. Any that are desirous to closely follow their mixtures by physical tests, or obtain true knowledge of the strength their product possesses, cannot ignore the value of micrometer measurements. For scientific research, at least, such methods must be strictly followed. Ideas for handling a micrometer are discussed at P, Fig. 97, page 496, and at Y, Fig. 106, page 514.

CHAPTER LXIII.

OPERATING TESTING MACHINES.

Obtaining true results or close records in testing is often assisted as much by careful work and system in operating testing machines as by correct methods in the moulding, casting, etc., of test bars.

In obtaining the transverse strength and deflection of bars cast flat they should always be laid on the bearing blocks the same way. The importance of this is realized when we consider that the down or "nowel" side of a one-inch area round or square bar can be made to show a strength of 300 to 400 pounds more by having the "nowel" side resting on the blocks than where the cope side is so placed, a quality clearly proven in Chapter LXV., page 476.

If bars are cast on end, it is well to have the down or upper cast end always pointed in one direction. To insure this in the methods advocated by this work, a small, flat depression is cast in the bars, so as to permit their always finding a good bearing at the same spot of the bars, as seen at X, Fig. 79, next page.

The same speed in testing should always be maintained as far as possible, as whether a bar is broken fast or slowly can make a difference in results. A comfortable speed, which can be always readily maintained, should be adopted. In obtaining tensile

strength of test bars, every care should be taken to prevent one side being strained or pulled more than another. The grip should be such as to cause an even pull all over the area of the specimen, in order to obtain the true tensile strength of the iron. See page 440.

Another essential in operating testing machines is that of applying the weight as steadily as practicable. At Fig. 80 is shown the upper section of a type of testing machine

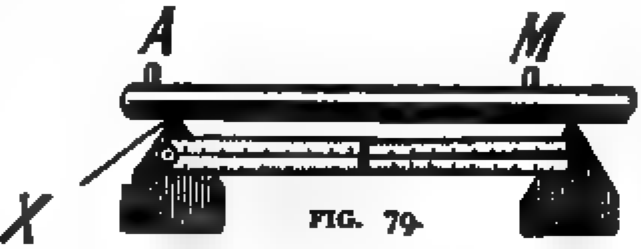


FIG. 79.

now being largely used, in which the oscillation of the beam F, from the lower stop H up to the upper stop K, in some cases may mean a load of 100 pounds, which if brought up or down quickly results in a strain like an impact blow. A good plan to follow in using a machine of this design is to place one hand around the stop at K. By this plan, less room is allowed for the oscillation of the weighting beam and the hand readily informs the mind of any upper movement, so that the sliding poise can be made to balance the beam before a bar could break to make it questionable within a one hundred pounds of just what is the true strength, by reason of the beam F rising suddenly to the stop K.

CHAPTER LXIV.

ROUND VS. SQUARE TEST BARS.*

The square test bar cast flat has heretofore been the method used. The author first advocated the use of a round test bar in an article in the *American Machinist*, June 6th, 1889. He is aware that the square bar cast flat has been the basis of the elaborate tables of transverse strength for use by our engineers and for publication in all our scientific text-books; yet in spite of all this, he would say the practice is wrong.

Metal in cooling arranges its crystals in lines perpendicular to the bounding planes of the mass, or, in other words, the crystals arrange themselves along the lines the waves of heat travel in passing outward from the casting as it cools off. To assist in illustrating this subject, I have taken the following description and cuts, Figs. 81 and 82, from Spretson's work on founding. Speaking of the cuts, Mr. Spretson says:

In the round bar the crystals are all radiating from the center. In the square bar they are arranged perpendicular to the four sides, and hence have four lines, in the diagonals of the square, in which terminal planes of the crystals abut or interlock, and about which the crystallization is always confused and irregular.

This is said to be very plainly exhibited by the effect

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* A revised extract of a paper read before the Western Foundrymen's Association, June, 1894.

of manganese in steel castings showing a contrast between round and square fracture.

A study of Figs. 81 and 82 impresses one with the importance of arranging for the greatest possible uniformity in providing for the radiation of heat from a test specimen, and also to afford it the most favorable conditions to arrange its crystals uniformly throughout its body. It requires no great stretch of the imagination to conceive what a great influence the simple matter of slight differences in the "temper" of sand in a mould may have in causing non-uniformity in the even texture of a square bar compared to the even structure possible in a round bar. Mr. John E. Fry, in a paper before the Eastern Association, May 2, 1894, condemning one-half inch square test bars, clearly illustrates the effect of a little variation in the "temper" or dampness of sand, often making square bars wholly unreliable as a test for the relative strength of any kind of cast iron.

FIG. 81. FIG. 82.

Before leaving Figs. 81 and 82, let me call attention to their clear exemplification of the necessity of casting test bars on end, in order to insure uniform cooling off. The heavy-work founder knows that metal first solidifies at the bottom of a mould, and if he is "feeding" a heavy casting, the metal, by solidifying at the bottom first, will gradually force his "feeding rod" upward, thus demonstrating that the greatest

line for radiation or line for heat to escape is upward, or through the "cope" of a mould. For this reason, if we would break a casting a foot square into halves down the center of its vertical position, as when cast, we would find the last spot to solidify would generally be about four inches from the top, or one-third its height below the cope surface. It makes no difference how small a body of metal may be, the same principle is applicable to it as to the large body, and goes to fully demonstrate the irregularity for a central point of latest solidification which must exist in a test bar cast flat. Then again, uneven cooling is bound to cause more or less internal contraction strain in a test bar. It must be evident that a test bar cast on end will have an even radiation from all portions of its surface at any height, and thus give to the bar the best uniform grain throughout any section and also the best opportunity to lessen strains so far as cooling off has any effect. More information on the necessity of casting test bars on end will be found in the next Chapter, page 475.

The nature of all cast iron is such that any elements in a mould possessing heat-conducting powers, that will either chill or make closer the grain of the metal in the skin or surface, are very effective in changing results in the strength and contraction of iron, especially in light castings or small test bars. There is a great difference in iron in its susceptibility to elements tending to chill. Some iron, if poured into a dry sand mould, would show a gray fracture, but if poured into an iron or green sand mould, would show at the surface a white or chilled iron, the depth of which depends upon the character of the iron, the thickness of castings,

etc. In Fig. 83, we see an irregular circle, outside of which we find the deepest close-grained sections at the corners A B. The lower the "grade" of the iron and the damper the sand the deeper will these corners chill or close up the grain of an iron. There is a limit to the extent to which combined carbon shown in the closing of the outer grain can cause strength in the test bar, where it is combined with a soft center or graphitic core as seen at D. A test bar can, by a radical difference in the grain of the core and outer body, embody such contraction strains within its own elements as to break with a lighter load compared with the true natural qualities of metal as exhibited by actual working results in castings or from a turned test bar. Degrees in "temper" or dampness of the sand comprising a mould have every influence in changing results in the corners of a test bar. A square bar is an erratic bar at its best; one cannot say what it will do in often showing different grades of iron to be decidedly the opposite of what a use of the castings would demonstrate. This is especially true where square test bars are cast flat.

FIG. 83. FIG. 84.

We will now turn our attention to the round bar, Fig. 84. It surely requires but little observation to impress one with the regularity of its outline comprising the surface or close-grained metal; and it appears like adding insult to injury to discuss the favorable

conditions it presents over a square bar in permitting iron to show a uniform grain in a test specimen. No one need accept the illustration of this question, as exhibited by the cuts, Figs. 83 and 84, as any founder can cast square and round test bars to ascertain the difference in the grain of two such fractures for himself.

For testing iron, by means of rough cast bars, I am at a loss to conceive how any one with the facts before him, as herein set forth, can scientifically support or argue for the adoption of a square test bar. When we consider the uniformity of radiation, crust and grain, that a round bar cast on end makes practical, and then look at a square bar cast flat, it does seem that we do not need any science, but that a little use of fair reasoning is all-sufficient to guide us aright in deciding which of the two forms is the more liable to most closely approximate comparisons of the strength or contraction of mixtures, etc.

CHAPTER LXV.

DISCOVERY OF EVILS IN CASTING TEST BARS FLAT.

At the meeting of the American Society of Mechanical Engineers, held in New York City, the week of December 3, 1894, the author, in a discussion on testing, briefly called attention to the series of tests seen on page 480. Before asking the reader to review the tests, the author would comment on the principles involved and what they demonstrate to us, in emphatically proving that certain practices followed to-day are not correct. It is well known that the past practice in moulding test bars has been upon the principle of casting them flat, and also that the form generally used has been a square or rectangular one, as against the round form cast on end, which the author is pleased to note is attracting much attention and is now being adopted by many as the only correct method to test the physical properties of cast iron. The author will now advance more proofs to show that the round test bar cast on end is the best method which we can adopt to reduce erratic results in testing to the minimum.

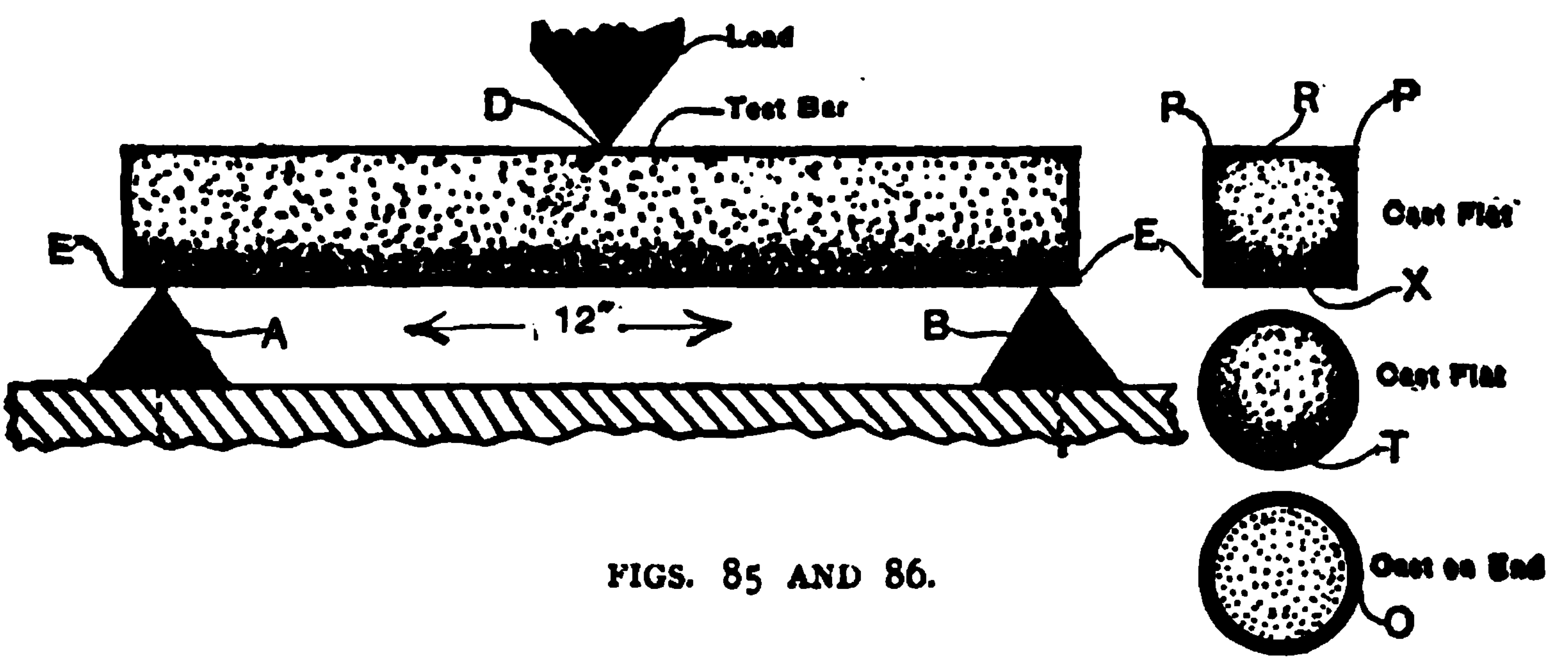
Early in 1894, the author discovered that in testing a bar cast flat for its transverse strength, by applying the load on the upper cast surface a much greater strength could be obtained than if the bar was

turned the reverse side up. I have found in experimenting with a large number of bars one-half inch square, one inch square, and one and one-eighth inch diameter, with supports twelve inches apart, that I obtained on an average 30 pounds more strength for a one-half inch square bar, 100 pounds in the one inch bar and 150 pounds in the one and one-eighth inch round bar. I wish these figures to be taken only as coming from an average from many tests in the respective sizes given, and with which as a principle the results have been very erratic.

I have found in a one-half inch square bar as much as 50 pounds difference in testing the two sides and in the one-inch square and one and one-eighth inch round I have found a few bars to give as much as 300 to 400 pounds of a difference, thereby presenting proof that casting flat any form or size of a bar admits of errors and jugglery and is wholly wrong.

I would state that in experimenting with testing on the lower and upper sides of test bars, they should always be moulded in the same flask, poured out of the same ladle and from the same gate. To prove my position on this question, I would first call attention to conditions which can be found by any who are sufficiently interested to experiment in this line. In Fig. 85, next page, is shown a side elevation of a bar resting on pointed supports A B, 12 inches apart, the distance which the author used in his experiments. The point of load is shown at D. The position of the bar is the same as when cast or lying in its mould. In examining such a bar, it will be found that the metal at the lower side or shell E E is generally denser, or of a closer grain, than that composing the upper half of the

bar. This is caused by the lower half being chilled more quickly than the upper half. This gives in the lower half of the bar, in a sense, more combined than graphite carbon, which results with iron not " white " in causing the " lower " half to be of greater strength than the upper half. But the degree to which this is affected in flat-poured bars is largely controlled by the difference in the " temper " of the sand, hardness of ramming, degree of fluidity, speed of pouring, and the quality of iron used. Since these conditions can-



FIGS. 85 AND 86.

not be always the same, results in testing flat cast bars are erratic. That one side of a flat cast bar will always be in line of giving more strength than another, is understood when we take into consideration with the above, the fact that in testing for transverse strength, we subject the under side of the bar to an extension or tensile strain, and the upper side to one of compression or crushing. If we have the densest or highest combined carbon side of a bar to resist the extension or tensile strain, it is reasonable to

expect it to stand a greater load than if we placed the most open-grained or weakest side to the extension or tensile pull. Another point which proves that there is a difference in the cross sections of the grain of iron in a test bar poured flat is that if we drill into the end of such bars there will be found, as a general thing, a tendency for the drill to work itself more to the top or weak side of the test bar, as more clearly illustrated in Fig. 87. I cannot conceive why the adoption of the round bar cast on end should not greatly lessen the causes for the past erratic results in testing, as my experience with these bars so cast makes it manifest how closely two bars of like area, which have been properly cast on end, in the same flask, with the same gate and out of the same ladle, will come to each other. Table 58, page 480, is an example of how closely round bars cast on end can record like strength. I would call attention to the test of twelve bars, comprising four one-half inch square, four one inch square and four one and one-eighth inch diameter, which were all moulded in one flask, poured with the same ladle from the same gate and cast flat, as seen page 480. There are also shown four one and one-eighth inch round bars, which are moulded two in a flask, upon the principle which the author advanced for casting test bars on end. These were cast out of the same ladle after the above twelve bars were poured flat. The ladle for pouring the above sixteen bars held about 150 pounds of metal. It will be seen by the examination of the Tables 55, 56 and 57, that all the

bars cast flat stood the greatest load, with their side which was down when cast being in extension when tested, and also that the greatest difference in this respect exists in the round bar. Again I would call attention to the fact that the results in all the flat cast bars were very erratic. This Table compares very closely in averages with a large number of tests which I have made on this point to satisfy myself as to the correctness of such results, and they always point in one direction.

A deceptive point which it might be well to notice in casting test bars flat is the chance it affords of making a test bar record too great a strength for an iron. Take a round bar cast flat and test it with its side cast down in extension, or as illustrated in Fig. 85, page 477, and one can record a greater strength than by any other method of casting; but where one desires to record the honest and natural strength of an iron, he should use the round bar cast on end. And by a comparison of the round bar cast on end with those cast flat, as seen by Tables 57 and 58, next page, the system which the author advocates is found to be one which will not permit a tester to obtain a greater strength than that which the iron truly possesses, nor admit of any jugglery in recording tests. When it is known that one side of a flat cast bar can often give 300 to 400 pounds more strength than its opposite side, there is surely an opening for deception and variable results. The mixture of iron charged for the test on next page was all pig metal of the analysis seen in Table 59. The analysis of the test bars shows the silicon to be reduced ten points and the sulphur doubled by re-melting the iron.

CHAPTER LXVI.

PHYSICAL TESTS FOR THE BLAST-FURNACE, AND THEIR VALUE.*

Progress in the science of either making or mixing iron requires a study of the physical as well as the chemical properties. The importance of a correct system for such tests, to make comparison possible between different furnaces, or the same furnace at different times, or with founders, is self-evident.

The first point to mention is the value of re-melting samples of the furnace-casts. The occasional re-melting of samples of casts, in a small cupola, cannot but aid the advancement of research, and serve as a check on chemical analyses, and often as a protection to the furnaceman, by enabling him to learn what the founder can do in changing the character of iron after it has left the furnace yard. A little cupola will also often be convenient for casting small pieces for repairs that may be needed between the furnace-casts, or when a furnace is out of blast.

A furnace man is often not informed of complaints concerning his iron until it has been all melted up; and then he has generally no remedy other than to inspect the castings claimed to have been made from

* Extract of a revised paper read at American Institute of Mining Engineers' Meeting, Pittsburg, Feb., 1896.

the iron complained of. As a founder, I know there are ways in which the original character of pig metal can be so altered in the foundry as to place upon the furnace man the blame for bad results for which he is not justly responsible. In such cases, the re-melting of a sample by him might often exonerate him. The expense of a small sample-cupola need not alarm any furnace man; he can erect one for $20. In fact, the author erected one, seen in Fig. 88, page 488, which went into blast January 17, 1896, which did not cost $6, and took but seven hours' labor of one man from the time ground was broken until the cupola was at work. A cast was made in ten minutes after the iron was charged. This cupola was made of an old shell, twelve inches in diameter and thirty inches long, which was being kicked around our foundry yard. It had been used a few years previously in an industrial street parade, for casting horse shoes, which were thrown to the people as the wagon rolled along, the blast being furnished by means of an old pair of hand-bellows. If iron can be melted under such conditions, in such a baby-cupola, no one need hesitate to believe that it can be conveniently done in a small cupola at a blast furnace, where all the blast required can be steadily supplied.

The following Tables, 60, 61 and 62, seen on next page, give chemical and physical tests of a furnace-cast, taken January 18, 1896, at the Spearman furnace, Sharpsville, Pa., and present one good form for such records:

TABLE 60.—PHYSICAL TESTS OF FURNACE-IRON TAKEN JANUARY 18, 1896.

No. of Test.	Contraction.	Deflection.	Strength	Fluidity.	Chill.	Diam'ter of Bar.	Strength per sq. in.
	Inch.	Inch.	Pounds.	Inches.		Inch.	Pounds.
1	6-64	0.12	2,300	4½	Not taken.	1.194	2,054

TABLE 61.—PHYSICAL TESTS OF CUPOLA-IRON.

No. of Test.	Contraction.	Deflection.	Strength	Fluidity.	Chill.	Diam'ter of Bar.	Strength per sq. in
	Inch.	Inch.	Pounds.	Inches.		Inch.	Pounds.
2	8-64	0.08	2,220	5	Not taken.	1.242	1,907

TABLE 62.

ANALYSIS OF FURNACE-IRON.		ANALYSIS OF CUPOLA-IRON.	
Silicon.	Sulphur.	Silicon.	Sulphur
Per cent.	Per cent.	Per cent.	Per cent.
1.02	0.034	0.81	0.056

NOTE.—The number of inches given under "fluidity" in this record is directly measured on the fluidity strip, seen at S in Figs. 90 and 99, pages 490 and 501.

The day is past for tolerating the blind, ignorant practice which we foundrymen followed, a few years ago, in mixing iron. The wonder is that we ever "hit" what we wanted, when we consider how deceptive is the fracture of pig metal as a guide to its true "grade." I am aware that only a few of our present founders have kept up with the progress of utilizing chemistry in mixing their iron; nevertheless, I say, when the furnace man has done his part, let the founder study to do his by calling chemistry to his aid, or else get out of the business and stop his growling about "bad iron."

There is no "bad iron." All can be utilized in some class of work or other. All that is wanted is a knowledge of its chemical and physical properties; and when the furnace man and founder understand these as they should, pig iron of any "grade" or quality need never be shipped in the wrong direction. It is simply a question of "carding the car" right, to have a furnace man clean his yards, and have no complaint about his iron, however "bad" he may occasionally make it, if he will but give a true analysis.

The foundry iron of the analysis in Table 62 is an excellent grade to make a machinable, strong casting for very heavy work, such as should not be under three inches thick in its lightest part, if all pig be used; but if the furnace man gets the wrong shipping card on the car, and some unprogressive founder receives the iron, and because it may look "soft" or "open-grained" tries to mix one-third scrap with it, for light or medium castings, he abuses the furnace man, because his castings crack and come out "white iron."

The cupola illustrated on page 488 is the smallest I know of, now used for practical purposes. Before taking a "heat" out of this baby-cupola, there was but one point that I felt doubtful about, in practice with such a small size for the work I intended it to perform, and that was, whether it would increase the sulphur, by re-melting, more or less than is done on an average in the large cupolas commonly used.

Owing to records kept at our foundry for the past three years or more of the analyses of the pig metal that goes to make exacting work (in which only shop-scrap can be utilized), and of the castings produced, we are enabled to judge fairly of the increase of sul-

phur by re-melting. I am pleased to say that the increase in sulphur caused by re-melting in the baby-cupola cannot be regarded as any higher than would result from re-melting in large cupolas. If anything, it is a little below what might be expected with fair coke. This is due to the iron not remaining in the baby-cupola as long as in ordinary foundry cupolas.

I will now proceed to describe a system of testing which I installed at the Spearman furnace, at Sharpsville, Pa., January 17, 1896, in which the managers took great interest, and which they are using with much profit to themselves.

The outfit includes one Olsen transverse testing machine of standard make, one cupola, two flasks, and chill pig-moulds with a test bar pattern and mould-board. An excellent feature of the whole equipment is that it need not cost over $100, including the testing machine. The price of such an outfit is no more than a furnace might have to pay for freight on one or two cars of condemned iron.

The cupola.—Fig. 88 shows the cupola used. It may have a "drop bottom," as shown, or it may simply rest upon a plain plate, and be tipped by hand to clean it out, after the conclusion of heats. The figure itself explains all details necessary to the construction and plan of charging the cupola, as seen on page 488.

The blast used is cold, so as to be the same as in foundry practice. It may require a few trials to find out what pressure of blast will give the best results. It should not exceed eight ounces pressure at the cupola, and will be found generally to work best at about six ounces, where two one-inch tuyeres are used. Where a low pressure of about four ounces can be

well maintained, I would advise the two tuyeres being about two inches diameter, and give this plan the preference over one-inch tuyeres with higher blast pressures.

The cupola should have its bed of coke well on fire before the iron is charged, and the latter should be distributed evenly all over the surface of the bed, the largest pieces being placed in the middle. I have melted one-quarter of a common-sized pig all down in fifteen minutes from the time it was charged. This is mentioned merely to show that the baby-cupola can deal very rapidly with chunks of iron.

The melted iron should be held in the cupola until one charge is thought to have been all melted down, before it is tapped out. A charge of iron may range from 20 to 50 pounds; and several charges may follow, having a layer of coke between them, from four to five inches in thickness. For a heat over thirty minutes long, some good flux may be advantageously used to make a thin slag, which could be run off at the tap-hole or at a slag-hole, provided for the purpose, about two inches above the level of the tap-hole. If but one charge of iron is being melted, let the lowest pressure of blast found permissible with utility be left on, up to the time that about two pounds of melted iron run out of the tap-hole. After this flowing of metal, plug up the hole and increase the blast pressure a few ounces, so as to bring down the iron quickly, and collect it in a good body, which will maintain its fluidity while it remains on the bottom bed before being tapped. In letting out the fluid metal, make a large hole and have a warm ladle to receive the liquid iron.

The lining used for the cupola is simply a coating of

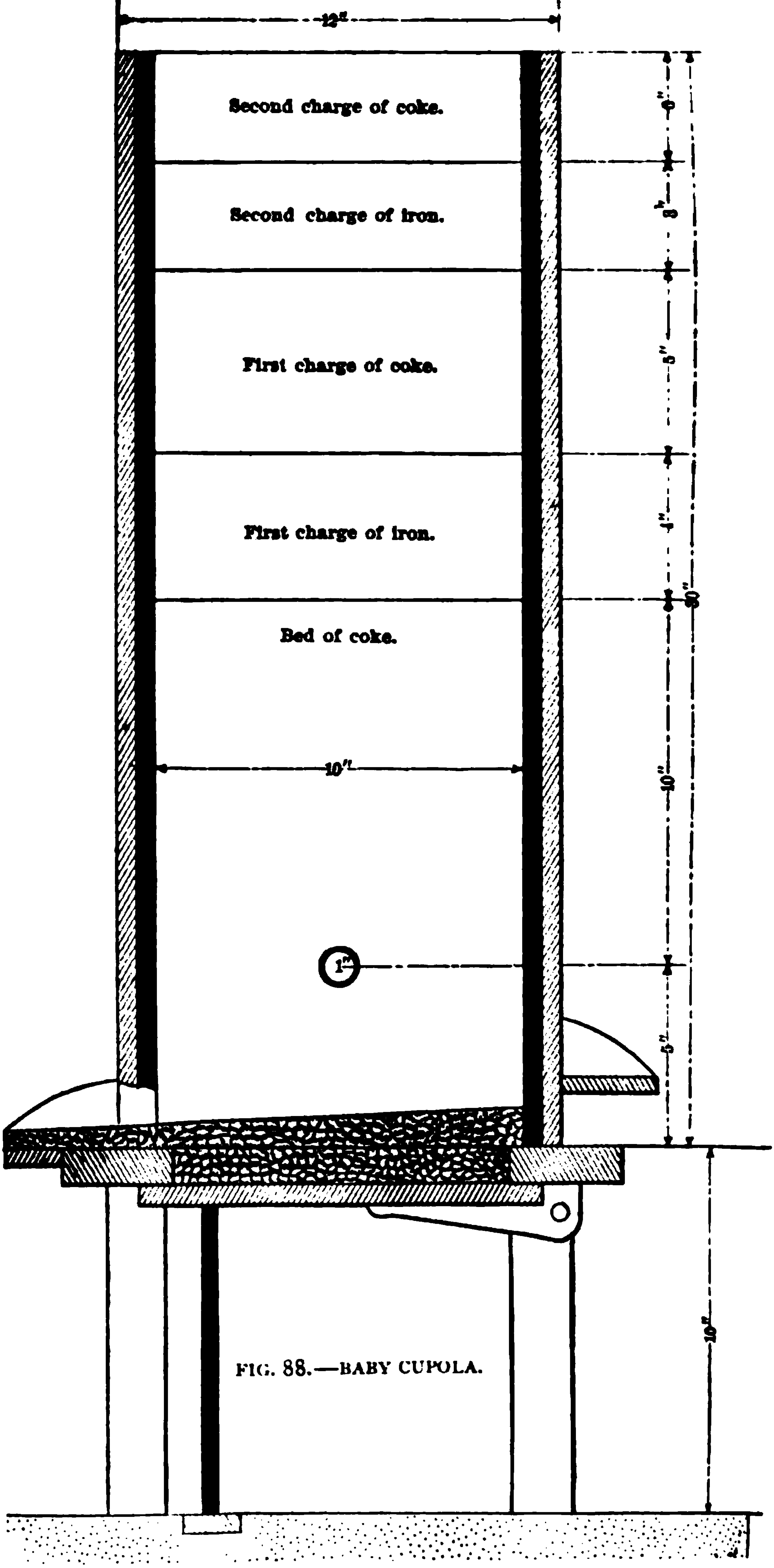


FIG. 88.—BABY CUPOLA.

fire clay, from three-fourths to one inch thick. It could, of course, be lined with fire-brick; the diameter of the shell being proportionately increased.

The baby-cupola shown is one which experimenters and college instructors could well use for giving instructions in melting, and will be of value for scientific research in all cases where the melting of small masses will answer all practical purposes.

Horizontal chill-mould, and the specimen obtained therefrom for testing contraction or chill, is seen in Fig. 91, page 493. Two sizes of these pig-moulds can be used, or only one, as the furnaceman may deem best, in following out experiments and tests, as described later on. Fig. 92 shows cross-sections through the middle of the respective iron moulds; and the larger cross-section shows also the tapering-rule, D, applied at the end of the mould, to measure contraction. It will be noticed that the thickness of these miniature pig moulds or chills is one inch. Any variation from this thickness would affect the depth of the chill. It is, therefore, necessary that care should be exercised to have always the same thickness in any standard chill pig-mould which might be adopted, that did not exceed two inches thick. The author does not wish to be understood as advising records to be taken of the chill from the test-specimens, in cases where very fine results are desired, unless note be taken of the fluidity of the metal at the moment the chill specimens are poured. This is done in the author's system by means of fluidity strips attached to test bars, as at S, in Figs. 90 and 98, and also in Fig. 99, pages 490, 496 and 501.

In Fig. 98 a chill piece will be seen at B, which is the same as shown at A, Fig. 97, and which is a form

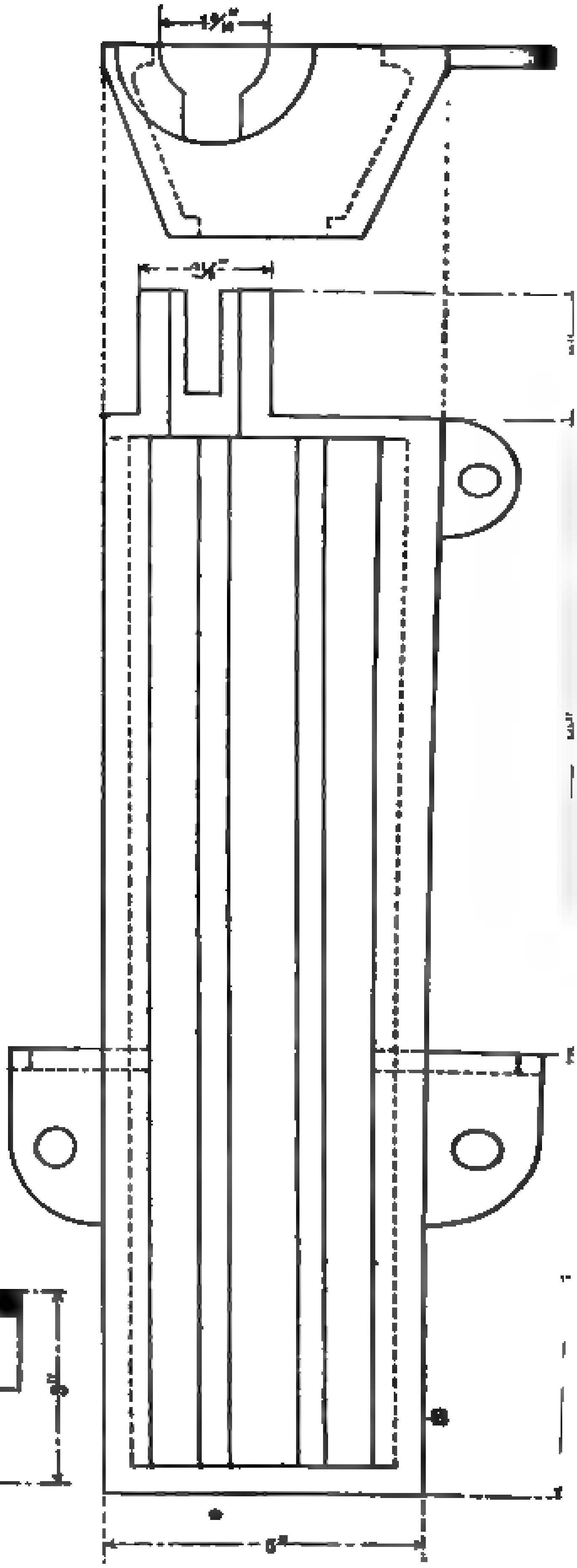


FIG. 90.

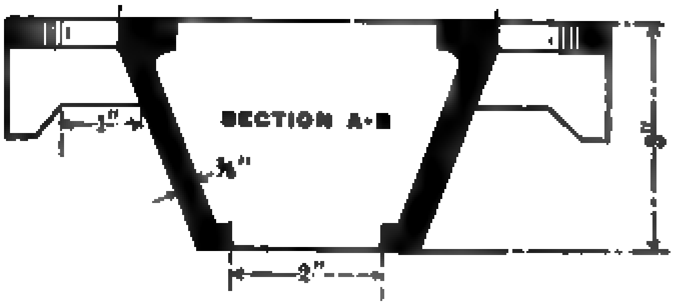


FIG. 89.

of chill used with the test bars shown, and is three-eighths inch thick by three inches long, and made of soft steel. Only one side or half of the test bar is here considered in measuring a chill for record. For iron above 1.25 per cent. silicon and no higher than 0.03 per cent. in sulphur, this system of obtaining chill-records indicated in Fig. 98 will work very satisfactorily. For iron lower in silicon or higher in sulphur, it may be often necessary to have a larger body of iron, in order to prevent a specimen being chilled all the way through. In such cases, chill-blocks, as shown in Figs. 91, 92 and 93, may be required to obtain chill-records. But if any value is to be attributed to the chill-records, the fluidity should be noted to be the same by eye or by the means shown in Fig. 98.

Fig. 93 shows a longitudinal section through the chill pig-mould of Fig. 91. The well at B is provided to prevent cutting the chill in pouring, and to cause the bar to pull towards one end in contracting, so as to permit the contraction to be readily measured by means of the tapering rule, shown at D. This test specimen, being twelve inches long, provides a convenient length for measuring the contraction, and can also be readily broken to note its fracture, or can be drilled to obtain samples for analysis.

The sections in Fig. 92 show that the bottom surface of the chill-mould is round, possessing no corners to cause any one part of the specimen to be chilled deeper than another, thereby causing internal strains and preventing natural contraction of the iron, owing to one part of the specimen being thrown into higher combined carbon than another. This consideration, the author believes, will cause any one making a

study of the subject to agree with him in advocating the principle of the round chill.

The tapering rule D, Figs. 92 and 93, is graduated on one side, as shown, to measure the contraction in the sixty-fourths of an inch. The rule is cut off on the small end at a point where it is one-sixteenth of an inch in thickness. From this the taper runs up two inches, at which point it measures three-sixteenths of an inch. The distance between the one-sixteenth and three-sixteenths points is then equally divided by six lines, as shown, so as to read to the one-sixty-fourth part of an inch, according as the space of contraction will permit the rule to be inserted between the chill-mould and the pig specimen, as shown. The lines being one-quarter of an inch apart, the scale can be easily read; but the rule could, of course, be graduated finer if desired.

The study of the element of contraction, as it can be defined from the pig specimens, Figs. 91, 92 and 93, will prove very valuable, and, in time, may enable a tester to know at a glance, without further research, the true "grade" of an iron. It can aid the furnace-man to detect deception, which is now known to exist in the fracture of "direct metal," and also to learn the true effects of re-melting iron, and what metalloids cause the greatest contraction in the iron.

At E, in Figs. 91 and 93, will be seen a depression of about one-quarter of an inch below the top surface of the chill-mould. This is to provide means for a "flow-off," to insure the chill specimens being always of the same thickness and prevent any iron running over the edges of the mould to retard free contraction in any manner. The chill-mould, of course, is set level.

FIG. 91.—CHILL PIG MOULD AND CASTING.

FIG. 92.—CROSS SECTION OF SMALL AND LARGE CHILL PIG MOULDS.

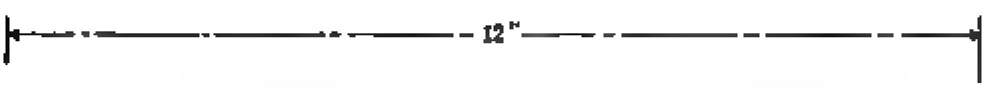


FIG. 93.—LONGITUDINAL SECTION OF CHILL PIG MOULD.

By using together the chill-moulds of both sizes, as shown in Fig. 92, an excellent illustration will be afforded of the reasons why many castings crack or pull apart, owing to the work being badly propor-

FIG. 94.—MOULD READY FOR CASTING.

FIG. 95.—FLASK AND PATTERN.

tioned. The small pig test specimen will always show a greater contraction than the large one. Such ill results in cracks, etc., are often placed on the furnace-man's shoulders by claiming that he had sent "bad iron." Should a furnace-man not care to use these

two sizes of chill-moulds at one time, he may, under proper conditions, adopt either for constant use. In the case of very low grades of iron it might be necessary to adopt the larger chill-mould, since in the smaller one the iron might "go all white."

In moulding test-bars for determining transverse or tensile strength or the deflection or stretch of an iron, the author has advised a very simple design of a flask and one which would not require a $4-per-day moulder to make the mould. Any intelligent laborer can be taught in a very little while how to mould and cast such bars successfully; and this can be easily done in about two minutes.

In starting to mould a single test bar, the round test bar pattern, L, and the fluidity-strip pattern, U, Fig. 95, are laid in the recesses of the mould board, Fig. 96, which has previously been solidly placed. The half-flask, H, Fig. 95, is then laid on the mould board, rammed up and rolled over, and then the "cope" is put on; clamps, as at K, Figs. 94 and 97, having been put on to hold the two parts close together while the cope is being rammed up. Before lifting the cope, the test bar pattern L is pulled out endwise. The cope is now lifted off; the fluidity-strip pattern, U, is drawn out; the cope is put on and clamped; and the mould is up-ended ready for casting, as seen in Fig. 94. The iron cup, A, Fig. 94, is used for the purpose of providing a wide funnel to pour into and keep the dirt from passing down with the iron. The slot cut in the iron end of the flask, as seen at E, Figs. 94 and 98, is to prevent the iron, as the mould fills up, from rising high enough to touch the under side of the cup. Should the metal in coming up

quickly, as it does, strike the under part of this cup, an explosion would occur, making the iron fly in all directions. By the plan devised such accidents are prevented.

MICROMETER

FIG. 98.—SECTION OF MOULD.

In cases where the fluidity and chill tests are not desired, and a plain round test bar only is wanted (which, for general purposes, will serve many ends), a plain round pattern, as at L, Fig. 95, page 494, which in the

rough is one and one-eighth inches in diam., or, in fine figures, 1.1284 inches, is all that is required. (Plans for casting plain bars are seen on pages 508 and 514.) It is well to have the lower end of this pattern made a little pointed for about three-fourths of an inch of its length, so as not to give a flat sand surface for iron to drop on, as in the case where the bar is entirely square on the end. In making this strictly plain, straight, round bar, the "cope" need not be lifted off, as the pattern can be pulled out endwise and the flask immediately up-ended, ready for casting (as seen on page 494), in less time than it takes to tell it.

Some might think a pattern rammed up on end in a wooden box (see page 514) would answer just as well. To do this and not have any swells on the bar requires considerable care in ramming the mould. By the plan here presented, no more time is required, and there is more assurance of unskilled labor obtaining a perfect, even, true round bar, free of all swells for its entire length, and without a joint mark on it. These are essential requirements for a test bar.

Should it be desired to cast only plain bars, without the attached fluidity-strips, the hole in the end of the flask, as at N, Fig. 98, could be placed in the center of the flask instead of where it is shown in the figure.

Fig. 89, page 490, gives all the dimensions of the single test bar flask shown in Figs. 94 and 95. Fig. 90 shows a single bar with its fluidity-strip S, as taken from a mould. The two projections shown on the bar in this figure, also at A and M, Fig. 79, page 469, constitute plans to be utilized to measure the contraction of such bars when they are moulded in jointed flask.

The simultaneous casting of duplicate test bars, illus-

trated in the next Chapter, shows the design of flask, mould board and patterns, with the improved "whirl gate," which is the latest the author has designed for "running" round bars cast on end. The method complete is one which the testing committee of the Western Foundrymen's Association has used with the greatest success in obtaining perfectly solid bars. As furnacemen advance in the work of physical tests, many may desire to take up questions which the single cast bar will not permit of investigation, requiring bars cast double, plans for which are cited in the next Chapter. Whether the exact plans presented in this paper be adopted or not, the principles upon which they are based cannot be ignored in the attempt to secure true physical tests at the furnace or foundry.

As a supplement to this Chapter, the author desires to again call attention to the importance of the adoption by the engineering and foundry world of test bars of a size that can establish a fair relation to the chemical analysis of iron, or accord with the commercial value which usage has given to degrees in its strength. By a study of Chapter LXIX., page 515, it will be seen that we should not use a bar smaller than of one square inch area. A few are still adhering to the use of one-half inch square bars, claiming that they have value in giving a "sensitive test." I would ask such, after having studied pages 444, 457 and 525, if they have not drawn the wrong conclusions, or if this does not truly mean that bars as small as one-half inch square or round are so "sensitive" to variations in the "temper" or dampness of sands and degrees in fluidity of metal, as to make them very erratic, and hence valueless to be used for a comparative test in any one single grade of iron, to say nothing about their inability to denote degrees of strength in the various grades used in general founding.

CHAPTER LXVII.

DESIGN OF APPLIANCES AND METHODS FOR CASTING ROUND TEST BARS ON END.

To successfully cast round test bars on end, when the contraction or fluidity is required in connection with the strength and chill of iron, it is essential to utilize a flask, etc., designed especially for such work. Figures 99, 100 and 101, pages 501 to 503, illustrate the design of flask, mould board and patterns with the "whirl-gate" which the author has designed to attain such an end. The test bar patterns and runner are illustrated at H, H, and E, Fig. 105, page 511. These patterns are also seen at D D and A, Fig. 99, page 501. The plan of drawing the patterns out endwise as shown avoids the necessity of any rapping of patterns; hence if the mould is fairly rammed and the pins of the flasks fit true, it will be evident that few, if any, joints will be seen on the bars obtained.

Moulds cast on end from a parallel pattern will always be largest at the bottom, owing to the head pressure. In making the test bars patterns D D, Fig. 99, for the first standard mentioned in Chapter LXIX., as an illustration, have them 1.1284 inches in diameter, at one end and 1.0884 at the other. In common

figures these would measure one and one-eighth inches diameter at the large end, and one and three-thirty-seconds of an inch at the small end, and of the same length seen in Fig. 99. By having a ring at the large end, as seen at H, Figs. 99 and 105, the smaller end will always be the down one in moulding, and in ramming the mould, do so to such a degree of hardness as to permit sufficient straining, due to head pressure, to have the castings come out closely alike as to size at the bottom and top.

It is well to mention at this point that should any desire to make their test bars in a "dry-sand" mould, they can readily do so, as there is no wood whatsoever connected with the flasks, thus making it practical to place the mould in an oven to be dried. For malleable and steel testing and some special purposes in iron, a "dry-sand" mould might often be found a very good method to adopt.

Referring to the question of "chilling," it cannot but be readily seen that as arranged by this system, the test bar and the chill must remain in close contact until removed by hand, hence truly recording the full chilling qualities of the iron. At V V, Fig. 102, page 509, can be seen the chill used in this system. It is simply two half-circles three inches long by three-eighths of an inch thick, having a hole drilled in them to fit over the pattern tips W W, Fig. 99. These chills are set on over the pattern before starting to fill the nowel with sand, and in shaking out, must, of course, be picked up and used as long as they last. They are made of a soft steel shaft, which, after being drilled or bored out, are then split as seen. See page 491.

In the case of very hard grades of iron, such as

would go "white" in the one and one-eighth round test bar at the chill end, when a chill was placed on the pattern in ramming the mould which embraces such iron as is used in car wheel, chill roll, and gun metal—the author would advise the adoption of the

FIG. 99.—WHIRL-GATE, TEST BAR PATTERNS AND CASTING.

second or third standard bars of one and five-eighths inches and one and fifteen-sixteenths inches in diameter described in Chapter LXIX. If the chill goes all "white" in the largest bar, he would use the largest chill block mould seen in Fig. 92, page 493, as a

standard. To find the depth of a chill with either of these round test bars, hold the chill end (after a bar has been tested) over a solid piece of iron and strike it as seen in Fig 103, page 509. A notch being cast in the chill end opposite the chill side, as seen at X, Fig. 79, page 469, permits the bar being readily broken when held as above described. To measure the depth of a "chill," consider only that portion turned "white"

FIG 100.—NOWEL HALF OF FLASK.

and the depth it has been chilled are to be defined by the eye.

Knowing that the degree of fluidity has an effect and should, for close, fine work be recorded in order to make intelligent comparisons, the author has in combination with other new features of this system provided at U U and S S, Fig. 99, an arrangement made possible with this system, by which we can measure the

height metal will rise in a long thin wedge. These fluidity and life measuring strips are ten inches long by three-fourths of an inch wide, as at S, in Fig. 98, page 496. The base of these strips measures one-eighth of an inch thick, and they run up to a knife edge at the top. They are a very sensitive barometer to denote both the fluidity and life of metal, as will be found by any one adopting the system. Having the fluidity strips poured in a vertical position, as arranged in this system in connection with the heavier bodies,

FIG. 101 —MOULD BOARD, BOTTOM PLATE AND COPE HALF OF FLASK.

prohibits any forced or unnatural pressure to be exerted, so as to have the strips falsely record the fluidity of metal when bars are poured. The metal cannot rise in the fluidity strips any faster than in the test bar, and hence the strips must have a gradual rise. Their measurement can be accepted as practical and representing the true fluidity and life of metal at the time it is poured. Take such fluidity strips and cast them flat (See Fig. 68, page 390); the length they " run " is greatly determined by the way they are

poured. Unless great care is used, one may be able to make them "run" fully four inches farther than if they were poured steadily, whereas, when poured vertically, as in the author's system, if there is a quick dash at any time it cannot raise the metal in the fluidity strips any faster than in the test bar moulds, thereby causing a natural and equal rise to truly denote the metal's fluidity or life at the moment the bars are poured.

To obtain the contraction of a bar, the distance between the points or tips V V, Fig. 99, page 501, is measured. These contraction tips are accurately cast in the mould by means of four projections forming part of the flask, two of which are seen at B B, Fig. 100. These projections "chill" one face of the contraction tips V V, thereby giving a clean face to measure from. The lower tips are given form by reason of a swell being made at the base of the fluidity strips, as will be seen at the lower V in Fig. 99. The upper tips are formed by having loose tip patterns placed in the recesses of the mould board as seen, in such a manner that the uppermost projection B of the flask is on the top side of the tip V. By this arrangement full freedom for expansion at the moment of solidification is permitted, as when this takes place it can extend its length downward in the sand forming the bottom of the mould. These contraction tips are cast twelve inches apart and will be found as arranged to provide positive points for obtaining the contraction of any "grade" of iron.

At A, Fig. 99, is seen the pattern used for forming the pouring basin and runner which leads to the "whirl-gate." At N is shown how the pouring basin and runner look before being broken from the test

bars. The reason for the recess seen in the end of the flask at E, Fig. 100, is to prevent the metal rising above that height at the end of pouring in order to give the metal any chance to form a "fin" between the top joint of the flask or over the top of its ends at H and thus still the more positively insure the casting's own weight pulling the contraction downward instead of the contraction pulling the whole body of the casting upward from the bottom of the mould, a factor which has been the cause of pulling the neck off from rolls or causing checks or total separation of parts in other kinds of castings. The cross bar in the flask is formed, as seen at R, Fig. 100, for the purpose of fitting over the runner where it connects with the whirl-gate's basin, to assist the same end just mentioned in compelling the contraction to follow a natural tendency, and not lifting the whole weight of a casting upward, as previously explained. At R R and O O, Fig. 99, are seen male and female pins and holes, which are arranged as shown so as to insure these two sections of the patterns coming together at true points, to make it impossible for the action of the rammer to distort them in any way.

In making the "whirl-gates" seen at T, Fig. 99, the operator must so proportion them that the runner joined to the basin A, Fig. 99, can carry the iron to the inlet of the "whirl-gates" as fast as they can deliver the metal to the mould, the idea being that as soon as the pouring is commenced, with either of the three standards, the upright runners are so proportioned that the pouring basin N can be kept full of iron, to prevent any dirt passing down the runner through the "whirl-gates" to the mould. Owing to the small

diameter of the one and one-eighth inch test bar, when this size bar is used, care must be taken in getting a good form to the "whirl-gate." If that form shown in the cut at T, Fig. 99, is closely followed, it will be found to give an excellent whirl to the metal as it rises in the mould, so as to bring any dirt that may by chance flow with the metal into the mould up to the top of the casting, and thus cause all test bars to be of a sound fracture when broken. The "whirl-gate" portion of the pattern seen on the left of Fig. 99 is made of brass or babbitt metal. The fluidity strips UU are cast in the main patterns after they are finished to the proper size. These fluidity strips can be made of any thin piece of wrought iron or steel. To strengthen the union of the "whirl-gate" portion of the pattern with the body of the test bars, brass or copper wire is laid in the mould and "cast in." The size of the "whirl-gate" where it joins the one and one-eighth inch diameter bar is about one-eighth inch in thickness by one inch wide. For the one and five-eighths inch, one and fifteen-sixteenths inches diameter bars, make this part of the gate one and one-quarter inches and one and one-half inches wide respectively, maintaining the same thickness of one-eighth inch as above shown in the one and one-eighth inch diameter bar.

It will be noticed that iron-perforated bottom-plates are used instead of wooden bottom boards to give a backing to the "cope" and "nowel" when up-ended in order to prevent the pressure of the metal from bursting the mould when cast at such points. To secure these iron bottom plates in place rapidly, strips of iron are pivoted at F F, Fig. 101, on the main part of

the flask as seen, then, by having a tapering projection cast on the bottom plates, as seen at X, Fig. 101, a few taps of a hammer on the binding strips F F are all that is necessary to secure the bottom plate in place.

Specifications often call for tests from turned bars. The author has arranged for such a test in a very simple manner, requiring but little machine work. At T, Fig. 104, page 509, is shown a bar having a swell cast on it. This can be made from six inches to eight inches long and of the diameter necessary to cause the "grade" of iron used to be readily machined to 1.128 inches, 1.596 inches or 1.955 inches diameter, so as to equal a one, two or three square inch area section and conform with the diameter of the rough bars given above for unfinished testing. The harder the grade of iron the larger diameter necessary at T to lessen the influence to chill or cause metal to be too hard for turning. But this should not exceed one and five-eighths inches diameter with the one and one-eighth inches diameter bar. Any iron that will be found too hard to be machined in this diameter of one and five-eighths inches of a swell, the second size and third size of a standard bar could then be utilized in having a swell cast on, half an inch larger in diameter than the rough bars called for. Whatever size of a swell is used, the same should be constantly used, in order to always have the same amount of stock to be turned off a test specimen. There are very few grades of iron which can not be machined from a body one and five-eighths inches diameter. The author has had bars with a swell of one and five-eighths inches diameter cast on one and one-eighth inch bars with grades of iron used in mak-

ing chill rolls, car wheels and gun metal, and found no difficulty in having them machined, as shown by the turned bars given with the cuts seen on page 274. The plan adopted to form these swells is simply to place half sections of patterns, as seen at N N, Fig. 102, over the regular test bar pattern when moulding them; then when the cope is lifted off, they are drawn separately from the mould. Of course, bars can be cast plain their full length and then have a recess about three inches long turned into them, instead of following the swell plan, wherever this is preferable.

The flask's dimensions for casting 1⅛ inch round bars, as seen in Figs. 100 and 101, are to be made eight and one-half inches by 17 inches inside measurements and four inches deep. To cast two, one and five-eighths inches or one and fifteen-sixteenths inches test bars, for the second and third standard, mentioned page 521, the only change necessary in the whole system is to make the flask ten inches to eleven inches wide on the inside. If desirable, one flask could be made to answer for moulding either the one and one-eighth inch, one and five-eighths inch or one and fifteen-sixteenths inch diameter bars, simply by having a flask 11 inches wide and the holes in the end of the flask at H, Figs. 100 and 101, made one and fifteen-sixteenths inch diameter, also the one and one-eighth inch or one and five-eighths inch test bar patterns to have a swell of one and fifteen-sixteenths inches diameter at the point where it would rest, or fill the hole H when the bars are being moulded.

When the strength only is desired, then bars can be moulded in any common jointless flasks for the length of the bars or by "bedding" them in the floor simply

by standing patterns on their end to ram them up on the plan illustrated on page 514. In gating and pouring such bars the metal should be dropped from the top through a "cope" in a manner not to strike the sides of the mould, and when two or more bars are moulded in one flask, their top pouring "gates" should be all connected to one pouring basin, made deep enough so as to keep the "gates" full of metal when the

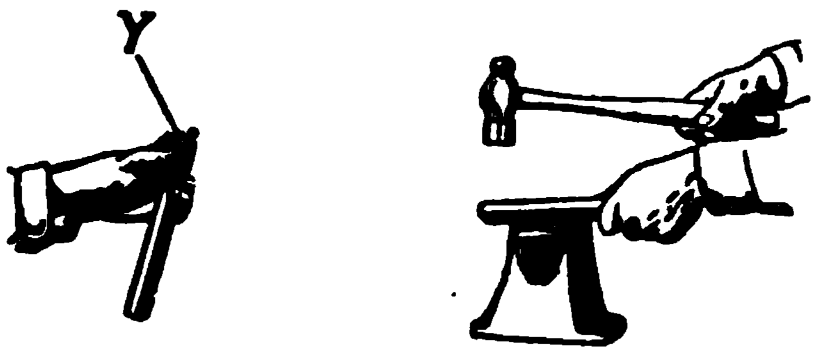


FIG. 103.

bars are being poured. By careful work, plain bars can be cast on end by this plan that will prove sound when broken. Plans for single bars are described, page 497, and plans for two or more plain bars being cast together are seen in Fig. 107, page 514.

FIG. 102.

Let it ever be remembered that, at the best, a test bar can only be used to make relative comparisons in the physical qualities of mixtures, and to properly secure these a size and form of a bar must be used that is not sensitively affected by the dampness of a green sand mould, and degrees in fluidity of metal. This demands that a bar be of round form, not less than one and one-eighth inches in diameter, and that such is best cast on end, as is displayed by reading Chapters LVI., LIX. and LXV.

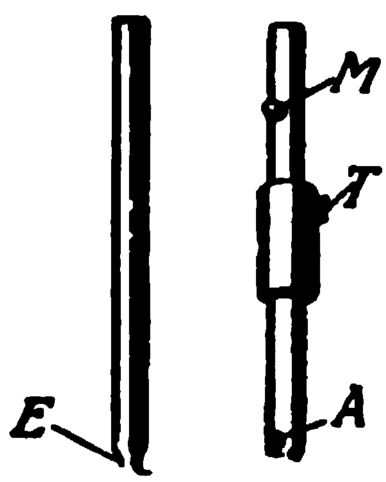


FIG. 104.

CHAPTER LXVIII.

MOULDING, SWABBING AND POURING TEST BARS.

In moulding test bars, every precaution should be taken to insure a uniform treatment at all times. The sand should always be of the same "temper," not too wet nor too dry, rammed regularly and of the same degree of hardness. The best way to attain this is to select some one intelligent man, who will make it his business to do all the moulding and casting of test bars which shall be required for any one department. The end to be sought in obtaining test bars is that they should be as near as possible the size of the pattern from which they are moulded. There are two factors affecting these results. The first is in the ramming and "temper" of sand, the second, in drawing the patterns. Past practice has been such as to require more or less jarring or rapping of the patterns before they were removed from the mould, and while one moulder might not do so to a perceptible degree, another might go to the extremes. A system to be favorable to making comparisons in one's own shop, or in the case of one firm with another, should be arranged so as to remove any semblance of the necessity of rapping or jarring patterns. For moulding test bars, some space as near the cupola as practical

should be devoted for this special work and there should be a place for every tool and all kept as neat and clean as possible.

After a mould has been rammed up, by the author's system, the round portion of the test bar pattern is then pulled out endwise, before the cope is lifted off, as seen in Fig. 105, this page. For a handle to draw out the test bars endwise, two inches of the patterns project outside of the flask as shown at H. The cope is then lifted off and the balance of the pattern and gates drawn out. After all loose sand or dirt has been blown out lightly with a pair of bellows, the cope is closed on, flask clamped, and then up-ended ready for casting, as seen in Fig. 106, on page 514.

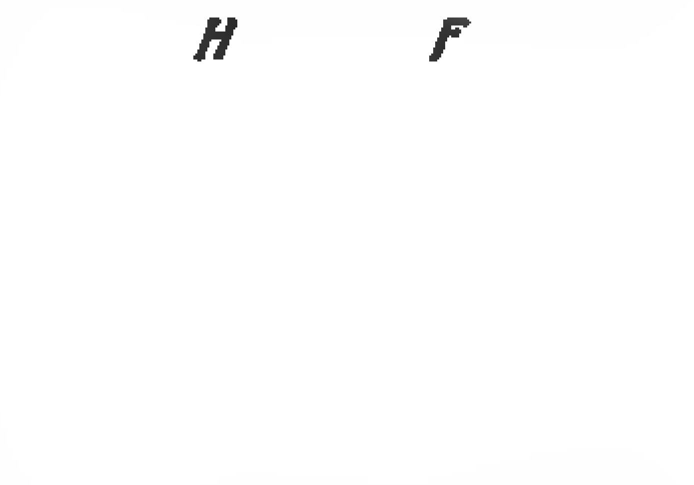


FIG. 105.

In drawing out the test bar patterns endwise, give them a half-twist around the mould before starting to pull the pattern straight out and they will come very easily, as it only requires a pull of from eight to twelve pounds at the moment of greatest power to draw them out. The pattern should be kept well varnished or bees-waxed, so as to prevent the friction of the sand wearing them away by a few years' use or cause them to become rough, making a " dirty mould." When the chills at A, Fig. 97, and VV, Fig. 102, pages 496 and 509, are used, care should always be taken that they

are not rusty or wet from any cause, as this could cause an explosion when pouring a mould. It is well to rub the chills with a very slight coating of coal oil or good machinery oil, where they are not in constant daily use.

The "swab" is something that should not be used in moulding test bars, if possible to avoid it, for the reason if sand were made wetter in some parts or spots of a mould than others, it affects the grain of the iron at that place, making it different from the rest, and hence it may be an element likely to cause erratic results and deception in recording the iron's true strength. If the sand is such that a swab must be used, it should be done with the greatest caution, especially at that part of the mould where the bar will break in being tested. The plan of pulling the patterns out endwise before the cope is lifted off, as devised by the author in his system, makes it unnecessary, with sand at all fit to mould test bars in, to use any water on the joint of the round part of the bar. The swab might be used a little around the gates, but it is best to be avoided if at all possible to make a clean, firm mould without doing so. Construct a swab so that the flow of water can be under perfect control by the lightest squeeze. To insure the stream or drops striking just the part or spot desired to be dampened, a good plan is to insert a piece of one-eighth inch wire, or long, thin nail, through the body of the swab, to project below it about two inches, as a guide to direct the stream. By using this design of a swab, it will be found that only the exact parts desired to be dampened will be affected, and the water will not be "slabbered" all over the mould, making parts like mud, as is often done by the kind of swabs some use.

In pouring test bars, use only "clean iron." Never take iron having slag or dross floating on top of it. Not only should the iron be clean, but a "clean ladle" should be used and skimmed off before pouring. While being poured it should be skimmed so as to prevent the oxide, which often rapidly forms on the surface, from passing into the mould.

With the use of round test bars cast on end, an intelligent comparison of one class of metal with another will demonstrate that there is a dividing line between soft and hard grades as to which would be the strongest with "hot" or "dull" poured metal. At present, that chiefly concerning us here is, at what temperature are bars best to be poured. As the founder chiefly makes tests for comparison, either to test his own mixtures or to furnish tests to compare with those of competitors, at the request of a middle party, it seems but reasonable and best that a temperature be followed that would best approximate such as is generally used. I would not advise a metal being too "hot" or too "dull," but something that would average about four and one-half inches up in the fluidity testing tips S and S, Figs. 98 and 99, pages 496 and 501.

Some founders might say their iron was hotter and would run up higher to a fine edge than that. I am not disputing these, but I do question whether they will always obtain the same high fluidity; and then again the iron may come out of the cupola all right, but owing to some "hitch" in the moulder getting to his "floor" ready to pour at some one time, could throw them off in their calculations. All elements and conditions considered, it is decidedly best to pour at a temperature while sure to run and make solid test

bars, still not so high but the temperature of day in and day out can be utilized and all " hitches " allowed for, so as to maintain a close uniformity. By endeavoring to maintain about the same temperature when pouring, it would go a great way in enabling the tester to attach more value to any comparison he might wish to make with his past record, or with others.

The cut Fig. 107 is a plan for casting plain test bars on end, so simple that any foundryman can find flasks, etc., to instantly change from casting flat to that of casting on end, should he desire to do so. E, E is the test mould. B, B are the "gates" c necting the pouring basin and moulds. M, pouring well. cope. R, nowel. For further scription, see pages 497 and

FIG. 107.

FIG. 106.

CHAPTER LXIX.

UTILITY OF THE TEST BAR AND STANDARD SYSTEMS FOR COMPARATIVE TESTS.*

Many lose sight of the real utility of test bars. They entertain the idea that they will give the actual strength, contraction or chill of single or unduplicated castings. The only way to obtain positive knowledge of these qualities is by making test bars of the same thickness and form, if possible, as those of the casting for which comparisons were to be drawn. In reality this would mean making two castings to be poured at the same time with the same iron, and breaking one to get the strength, etc., of the other. The true utility of the test bar is simply comparative, to define differences that may exist in mixtures of the various "grades" of iron, or, in other words, all that the test bar will do is to denote the strength, etc., of the iron which is poured into the mould; and what the shape and size of that mould would do to distort the physical qualities of the iron from agreeing with what the test bars have recorded, is largely left for experience to guess at or comparative tests of broken castings to define.

* Revised paper presented by the author to the Foundrymen's Association, Philadelphia, Pa., December 2, 1896.

Where there are many duplicates, as in the manufacture of car wheels, pipes, etc., we can, by breaking a few castings, and test bars that have been cast out of the same ladle of iron, obtain a very fair base as a standard for future comparisons of what may be expected in the castings themselves from test bars from future mixtures. This is not saying that single castings made of the same pattern, cast at different times, could not have any comparative knowledge imparted of their strength, etc., by reason of using a proper test bar, cast with the same ladle of iron. If a single casting stands desired usage and the builder or buyer has a record of test bars that was poured of the same iron with the casting, he generally can rest fairly assured that, if at any other time he should get another casting made from the same pattern with a test bar that would show a similar strength, he would have a casting that would be fairly equal in strength, etc., to the first one made. And again, the use of these can often prove protection to builders that have machines broken by claimants for unjust damages, as, for instance, in the case of punch and shear castings, which are often broken by reason of carelessness on the part of workmen or attempts being made by the proprietors to utilize a machine above the strains guaranteed. For if the builder can prove that previous castings, which had tests recorded from test bars, had stood the guaranteed strains to compare closely with the casting that broke, he cannot be far out of the way in maintaining the position that the close comparison of all his test bar records justified him in assuming that all castings made from that one pattern should be closely alike, for the reason that they can be classed under the head of

duplicates similarly as cited above for car wheels, etc., the only difference being that these single castings are not cast in large numbers and may have months intervening between their production, so that in a practical sense single castings can, when they are occasionally duplicated, have the test bar records accepted to denote their physical qualities in a comparative manner, as where any number of castings are steadily or daily made from the same pattern.

The value of a test bar has never been appreciated, in its right sphere, to the degree it should be, but the author believes the time is not far distant when the machine shop will be as much interested in the test bar as many engineers and founders are today; and when this time does come, the utility of a standard system will be strongly forced upon us and no doubt an effort will be made to establish and recognize standards for physical tests. How are we going to be able to make intelligent comparisons with our own records or those of others, where we find bars as small as one-half inch square to two inches square being used, and some of rectangular form, and again it can be said, in all kinds of lengths, from a foot up to four feet long, so that we practically find hardly two founders using the same form or length of a bar, or builders and engineers exacting the same character of tests? Some will say that the difference in both the length and area of such a variety of bars could be computed to strength per square inch, in making comparisons. It can be shown (see Chapter VI., page 463,) that there is about as much difference to be found in formulas for computing such variations as is found above in test bars, and also that so eminent and able an authority as Professor C. H.

Benjamin, of the Case School of Applied Science, has shown that present recognized formulas are unsuited and incorrect for figuring the strength of cast beams, etc.

The prevailing practice of recording tests to-day may, in some cases, where test bars not less than of one inch area are used, be accepted as an approximation in so far as relates to a firm's own practice in making comparisons for mixture, with permanent hands, but should a firm desire to bring in a new manager or tester, who has been guided in rulings or records obtained from other shop practice or systems, his past experience will prove of very little value to him; hence the firm must lose in many ways before the new man is enabled to be rightly guided by information which he can deduce from his new system. Then, again, a manager or tester in making any changes from one work to another is also a loser and is subjected to the same inconveniences, etc., just mentioned. This shows us that both sides can be heavy losers, saying nothing as to what is lost by their not being able to make intelligent comparisons with the outside foundry and engineering world, or with blast furnaces from which large quantities of pig metal must and should be intelligently purchased. Present practice shuts us up like a clam, and makes us dead to all the benefits which a standard of physical tests could insure. Progression demands something broader and of more correct utility than the present practice insures.

In reviewing tests recorded of test bars or castings in our engineering text-books of the past, we find the practical utility of the same to be largely lost, for the reason that there is no base presented upon which to formulate mixtures, to duplicate fairly the "grade" of

the iron comprising the casting or test bar whose strength, etc., has been recorded. If for each test of all such castings or test bars we had a standard system, we could then by referring to the tests of any mixtures in our own practice which had recorded similar physical qualities in a test bar, be at once in the most favorable position attainable to produce a similar casting, having like physical qualities. Some might suggest the chemical test of the castings being recorded in order to give a base for making comparisons and duplication of like castings. This would work admirably in most cases, but of the two methods the physical test is often more economical and practical for adoption by many founders, for the reason that there are some who can afford to conduct physical tests, but who cannot maintain a laboratory with its chemist, or engage outsiders. Even where founders are equipped with laboratories, the physical tests are necessary as a "hand-maid," to tell what is being achieved, and still further argue for the advisability of a standard system of physical tests.

If there were no difference in the "grade" of an iron as daily produced by founders, then any record of the strength, etc., of mixtures would be alike and we would not require any physical tests, but when we consider mixtures of iron can be made ranging all the way from 600 to 4,000 pounds, with one square inch area bars twelve inches between supports, it plainly illustrates the benefits to be derived by accompanying a casting with tests obtained from the same ladle or iron by means of suitable test bars, whether the strength is obtained by means of transverse or tensile tests to make comparisons.

Because the one and one-eighth inch round bar is large enough to not have its carbon severely distorted to make tests erratic or belie the ruling power of the percentage of "iron" in the metal, by the chilling influence of a green sand mould, and also because it is not so large but that the strongest "grades" can be tested for comparison with weak "grades" on low priced testing machines,—these are the main reasons why the author contends for the universal adoption of the one and one-eighth inch round bar as one standard for making comparative tests. Having shown in previous papers (see Chapter LX., page 458,) that the one and one-eighth inch round bar is fitted to record degrees in the strength of cast iron to largely agree in a comparative way with the commercial value attached to the strengths of the various mixtures ranging from stove plate up through light machinery, heavy machinery, car wheel, chill roll and gun metal, the author would now refer to other two sizes, one and five-eighths inch and one and fifteen-sixteenths inches diameter as being also well fitted for recognition as standard bars. These two latter sizes of bars are best utilized by founders who may make mixtures containing less than 1.00 in silicon and about .04 in sulphur. For those above 1.00 in silicon and below .07 in sulphur, the one and one-eighth inch diameter bar will be found to record very good comparisons in degrees of strength.

It is to be understood that while either size of the above three proposed standard bars would not err much in recording true degrees in the strength, deflection, contraction and percentage of "iion" in the various "grades" (see page 525), where comparisons are to be made in any one "grade" or in

all of them, the same size bar must be used. One size bar cannot be used for one per cent. silicon iron and then dropped and another taken up to test percentages above or below this. (See Chapter LXVII., page 507.) Whatever size of a common sense bar the testers use, in making comparison through any range of work, they must stick to that one, and then, if they desire to make comparison with outside records that have been obtained with standard bars other than the one size they use, they would then be compelled to make tests with the same size of bars which was used to obtain the outside test. Of course, if a firm desired, they could cast the three sizes of bars together, mentioned on page 520, with the same ladle of iron, and thus always have at hand records by which they could make comparisons on a moment's notice, with any outside tests that had been obtained with either of the three standard sizes of bars mentioned herein.

The following Tables, 63 to 68, pages 523 and 524, display tests of the author's proposed three sizes of standard bars, accompanied with a chemical analysis of the various mixtures shown to still increase their value. A study of these Tables (combined with those of Chapter LX., page 448), the author believes, will sustain him in his advocacy of the 1⅛-inch, 1⅝-inch and 1$\frac{15}{16}$-inch round test bars as best fitted for and to maintain a standard of comparative physical tests.

The tests presented are obtained from the actual mixtures used for pouring castings in the various specialties mentioned, and, as seen, are arranged in the order of their strength. Double the amount of tests were made, but those shown illustrate the relation of the different areas in strength per square inch as

well as large quantities could, and make study an easy task to readily demonstrate their utility, as being all-sufficient for standard comparative tests.

The tests shown are all of solid bars cast on end, and they illustrate among other valuable features the fact that the two and three square inch area round bars record a greater strength per square inch than the one square inch area bars; and were it not for the fact that the round bars of two and three-inch square area require costly testing machines, they would be the best size for all to adopt as standards. Nevertheless this series of tests shows conclusively that no one should use a test bar smaller than of one square inch area with the expectation of making any fair comparisons of degrees in the strength, etc., of his irons. While the one square inch area round bar shown does not record the high strength for strong metals that the larger bars do, it is made very evident that they do record degrees of strength sufficiently well to be used for a comparative test by any that may desire to adopt it, a fact also demonstrated by the specialty tests as seen in Table 51, page 456, showing a gradual rise, in denoting degrees of strength ranging from 1,480 to 3,686 pounds per square inch.

The test bars shown in this Chapter were cast during the month of May, 1896, and were kindly supplied by the foundries of the Lloyd-Booth Co., Youngstown, Ohio, Philadelphia Roll & Machine Co., and A. Whitney & Sons, both of Philadelphia, Pa., and the Shenango Machine Co. and Graff Stove Foundry Co., both of Sharon, Pa. The test of "Bessemer," Table 68, was cast by the author.

Tables 63, 65, 66, 67 and 68 were tested by Prof. C. H.

Benjamin at the Case School of Applied Science, and those of Table 64 by the Riehle Bros., of Philadelphia, Pa. The strength per square inch is obtained by dividing the actual breaking load by the area of the bar, at its point of fracture. (For rule, see page 463.)

TRANSVERSE TESTS OF SPECIALTY IRONS WITH ONE, TWO AND THREE SQUARE INCH AREA TEST BARS.

TABLE 63.—CHILL ROLL IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
1	1 1/8"	1.140"	3,250	1.021	3,183	0.105
2	1 5/8"	1.655"	9,500	2.151	4,417	0.090
3	1 15-16"	1.968"	15,250	3.042	5,013	0.085

TABLE 64.—GUN CARRIAGE METAL.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
4	1 1/8"	1.122"	2,780	.988	2,812	0.100
5	1 5/8"	1 664"	9,250	2.174	4,254	0 110
6	1 15-16"	1.859"	11,820	2.714	4,355	0.100

TABLE 65.—CAR WHEEL IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
7	1 1/8"	1.174"	2,200	1.082	2,033	0 053
8	1 5/8"	1.697"	8,100	2.244	3,610	0.070
9	1 15-16"	2.008"	13,500	3.167	4,263	0 072

TABLE 66.—HEAVY MACHINERY IRON.

No. of test.	Diam. of bar. Common rule.	Microm-eter.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	De-flection.
10	1 1/8"	1.187"	2,800	1.1066	2,530	0.092
11	1 5/8"	1.705"	7,100	2.282	3 111	0,072
12	1 15-16"	2 001"	11,900	3.143	3,786	0.079

The chemical analyses seen in Table 69 were kindly furnished by Dickman & Mackenzie, of Chicago, and Dickman & Crowell, of Cleveland.

Aside from the attention which has been called by this paper to various points in the following tests, there are two factors which many will be at a loss to understand. The first is the break in the gradual in-

TABLE 67.—STOVE PLATE IRON.

No. of test.	Diam. of bar. Common rule.	Micrometer.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs.	Deflection.
13	1 ⅛"	1.182"	2,520	1.097	2,288	0.117
14	1 ⅝"	1.745"	6,050	2.391	2,530	0.078
15	1 15-16"	2.047"	9,900	3.288	3,011	0.081

TABLE 68.—BESSEMER IRON.

No. of test.	Diam. of bar. Common rule.	Micrometer.	Breaking load.	Area of bar.	Stre'gth per sq. in. in lbs	Deflection.
16	1 ⅛"	1.175"	2,150	1.084	1,983	0.100
17	1 ⅝"	1.698"	5,500	2.263	2,430	0.100
18	1 15-16"	1.991"	8,900	3.112	2,860	0.085

TABLE 69.—CHEMICAL ANALYSIS.

Specialty.	Silicon	Sulphur.	Mang.	Phos.	Comb. Carbon.	Graph. Carbon.	Total.
Chill Roll..........	.84	.071	.285	.547	.61	2.45	3.06
Gun Metal..........	.73	.059	.408	.453	.76	2.47	3.23
Car Wheel..........	.78	.132	.306	.364	1.07	2.36	3.43
General Machinery......	1.30	.053	.224	.433	.58	3.31	3.89
Stove Plate.........	2.47	.094	.265	.508	.19	4.00	4.19
Bessemer Iron................	1.52	.059	.326	.083	.49	3.73	4.22

crease of strength of the 1⅛ bars, which is displayed by test No. 7 being weaker than tests Nos. 4 and 10. This is due to the high sulphur in the iron when in this small body of 1⅛ inch diameter, causing the combined carbon to overreach its limit for gradually increasing the strength of the 1⅛-inch bars, as shown in tests Nos. 1, 4, 10, 13 and 16. The second factor is that shown by the low strength displayed by the "Bessemer" iron shown in Table 68. This is chiefly caused by reason of the low phosphorus necessary to make Bessemer iron. Had this metalloid and "iron" been near the percentage seen for machinery as shown in Table 69, the strength of the test bars in Table 68 should have equalled somewhere that of Table 66.

A very extensive and valuable discussion was held upon the merits of the above paper and largely endorsed the author in his views of the necessity for a standard, also in the quality that test bars should not be smaller than of one square inch area. An important point given prominence to was that of Mr. Asa W. Whitney, of the A. Whitney & Son Car Wheel Works, in which he demonstrated that the amount of iron in metal was that to chiefly denote its strength, the more iron the greater the strength (which must not approach too near to pure iron, as described on pages 258 and 306). To illustrate his views, he gave the following, Table 70:

TABLE 70

	Chill roll.	Gun metal.	Car wheel.	General machinery.	Stove plate.	Bessemer iron.
Iron	95.197	95.120	94.989	94.100	92.473	93.782
Strength of largest bar	5.013	4.355	4.263	3.786	3.011	2.860
Relative strength	100	87	85	75	60	57
Relative estimated strength	100	86	84	77	81.5	68

Mr. Whitney also discussed at considerable length the practicability of estimating the strength of iron by the analysis, and was of the conviction that the day was not far distant when such would be generally accepted as being practical. In this the author agrees with him. It will be well at this point to state that the general way of obtaining the "iron" in cast metal is by deducting the totals of the silicon, sulphur, manganese, phosphorus and carbon percentages from the sum of 100. If there have been any errors in getting these various percentages, it would, by the above calculating process, be then thrown all on to the "iron," so in order as a check to positively determine the "iron" in metal, it is really necessary to weigh up the "iron" after the other elements are taken away from it, when making the analyses, or make an analysis of the "iron" only and then let such be recorded in a column adjoining that of the totals for the carbons. Of course, wherever the "iron" is not shown in analyses, it can by the above calculating plan be estimated as far as such is to be valued, and thus be made to serve for the Tables seen on pages 255, 280, 320, 327, 338 and 396 by any desirous of doing so. There was considerable discussion upon the question of formulæ, which was participated in chiefly by Mr. J. S. Sterling, Mr. Christy, Mr. Prince and Mr. Davis and Mr. Wiggins, the latter strongly supporting the well-known Johnson formulæ. There seemed to be a misunderstanding as to the formulæ which the author presented for obtaining the strength per square inch, by dividing the actual breaking load by the area of the bar, that such meant to be applicable to any length, etc., of a bar. This formula is only advocated for figuring comparative tests where one

size and length of a bar is used, as can be seen by referring to pages 461 and 517. The author would here say that until the engineering world can present something better to be recognized as a standard, he will continue to use and advocate the formulæ herein given, as he has failed to find any which for the purpose intended are any more simple or correct in their figures or conclusions. Mr. Whitney's own declaration and estimation of what the analysis of the "iron" determines in degrees of strength, as shown by Table 70, page 525, strongly prove that the author's formulæ will give results (to agree closely with Mr. Whitney's rule) not far out of the way in defining the commercial value generally attached to degrees in the strength of "grades" or all that is practical to be expected from any formulæ which, at their best, are but an approximation, as when we come to figure the strength of iron in different sized bodies, from some base which standards in test bars might define, we will always have to acknowledge that figuring ratios and actualities are two different qualities in their relation to defining the true strength of cast iron. The above discussion in full can be found in the *Iron Age*, Dec. 10, 1896.

While referring to Mr. A. W. Whitney's commendable researches, the author would also mention that in a paper on "Chilled Iron," read before the Philadelphia Foundrymen's Association, Jan. 6, 1897, —published in the *Iron Age*, Jan. 14, 1897, Mr. Whitney shows that the transverse strength, also the resilience of "chilled iron," is the greatest in the direction of the chill crystals. He also shows that "tumbling" or "rumbling," "chilled" or "white" iron is not as effective in increasing the strength of iron, as is the case with medium or gray irons, qualities cited on pages 437 and 542.

CHAPTER LXX.

ONE HUNDRED ITEMS TO BE REMEMBERED IN MAKING, MIXING, MELTING AND TESTING IRON.

The following one hundred items cover, in a concise form, a broad experience, extensive research and careful conclusion of some important features and of varied tests to be found embodied in this volume, all of which are of value to be studied and remembered by any interested in making, mixing, melting or testing cast iron.

MAKING IRON.

1. **Modern furnaces** make from 150 to 650 tons of iron per day. For every ton of iron produced, about two tons of ore, one ton of coke and nearly half a ton of limestone are charged into the furnace. For a production of 500 tons of iron per day, this would call for about 1,750 tons of material to be charged into a furnace every twenty-four hours.

2. Everything that goes into a furnace making iron must pass off as a gas, molten metal or slag. For every two tons of iron produced, over one ton of slag is generally made.

3. It generally takes from 10 to 14 hours for a charge of stock to pass through a furnace and produce molten metal, if a furnace does not "scaffold," which is often caused by chilling or expansion of the ores in becoming heated.

4. With a temperature of 60 degrees F., and the

barometer at 30 inches, air weighs about 1.815 parts as much as water. The weight of blast passing through a furnace to produce iron is greater than that combined of all the fuel, ore and lime charged.

5. There is cold blast, warm blast, hot blast and superheated. Warm blast has a temperature from 250 to 400 degrees F., hot blast from 700 to 1,100 degrees F. Above 1,100 degrees F. it is superheated blast.

6. Cold, warm and hot blast are all used for making charcoal iron, and hot blast for coke and anthracite iron, with a temperature generally ranging from 800 to 1,200 degrees F.

7. **High temperatures in blast** generally mean economy in fuel, convenience in working and increase in the output. The same weight of cold blast, fuel and conditions that would produce a hundred tons of iron in a given time will, by simply heating the cold blast to a temperature of about 1,100 degrees F., increase the output of a furnace from 50 to 100 tons.

8. The more even temperature that can be maintained in a furnace, the better the result in all that pertains to economy and success in making iron. If positiveness could be insured in this line, the tendency to scaffolding and irregular workings would be largely overcome. Blast pressure used for furnaces ranges from 6 to 24 pounds per square inch, while that of cupolas is only from 6 to 24 ounces.

9. A hot or "good working" furnace sends the silicon into the pig and the sulphur into the slag. A cold or "poor working" furnace sends the sulphur into the pig and the silicon into the slag.

10. **Carbon** in iron is obtained from the fuel used to smelt the ore in the furnace.

11. **Silicon** in the iron is chiefly derived from the silica in the fuel and can be absorbed by iron as high as 20 per cent.

12. **Sulphur** in iron is chiefly obtained from the fuel and ore. The flux may sometimes give up a little.

13. **Phosphorus** is obtained from the ore, flux and fuel; **Manganese** from the ore.

14. **Silica** in the slag is silicon in the iron. For every pound of silicon not taken up by the iron in making it, or reduced in re-melting, about two pounds of silica is carried off as slag or dross by converting the silicon into an oxide.

15. **A "hot furnace,"** or high temperatures, increases the silicon and manganese and reduces the sulphur.

16. **"Banking a furnace"** means a temporary stoppage, with combustion smothered from one to eighteen months.

17. **"Blowing out"** means to stop regular charging and after all ore is reduced to iron extinguish all fire.

18. **"Shoveling out"** means cleaning out all the refuse of ore, fuel, lime and dross in a furnace to prepare for a fresh start.

19. **"Blowing in"** means starting in to make iron after a period of "banking,"or the instituting of melting in a new or old furnace.

MIXING AND MELTING IRON.

20. **Chemistry tells us** the metalloids we must use to obtain desired results in the "grade" of an iron.

21. **Carbon** is the principal constituent in cast iron; it exists in two forms, graphite and combined. The more graphitic and less combined carbon the softer the iron; the reverse to make it hard.

22. The state of the carbon in being combined or graphitic is influenced by varying percentages of silicon, sulphur, phosphorus and manganese, and rate of cooling of the casting.

23. Variations in the percentage of combined carbon are more effective in changing the grade of an iron than equal variations in graphitic carbon.

24. An increase in combined carbon causes deeper "chill," greater "shrinkage" and "contraction"; a decrease the opposite effect in the three elements cited.

25. **Sulphur** increases the fusibility of iron by reason of hardening the iron, and can strengthen; and then again by its raising the combined carbon above the limit best for strength, it can greatly weaken it.

26. It takes less sulphur than any other metalloid to change the "grade" of an iron. One part of sulphur can neutralize the effect of eight to twelve parts of silicon.

27. Iron can readily absorb sulphur up to .30 per cent. Twenty-hundredths of one per cent. of sulphur in ordinary foundry mixtures is sufficient to injure almost any castings made, excepting sash weights and the like.

28. High sulphur in molten metal can cause "blow-holes" in castings, unless poured fairly "hot" and the mould is not one of a character to quickly solidify the iron.

29. Increased sulphur, with silicon, etc., remaining constant, can cause excessive shrinkage as well as contraction, the former being the cause of shrink holes, the latter internal strains and cracks in castings.

30. Any increase of sulphur also increases depth of chill. By decreasing the sulphur, with silicon, etc., constant, the opposite in effect cited above with "chill," as well as "shrinkage" and "contraction" will result.

31. The slightest change in sulphur is very effective in changing the character or grade of iron; for this reason great care in being watchful of its contents in fuel, etc., or iron to be re-melted is very essential.

32. **Silicon** is the softener. By a judicious use of it very low grades of scrap or hard iron can be re-melted with it, to make soft castings of good strength. Four per cent. silicon iron mixed with 80 per cent. of ordinary non-chilled or un-burnt scrap iron having over 3.10 per cent. of carbon will generally make soft, machinable castings in work above one inch thick.

33. Silicon, if not carefully used, is a great poison to the strength of iron. It can weaken castings more than any other metalloid, as generally found in ordinary castings.

34. Not only is silicon the softener of iron, and a great element in cheapening the cost of mixture, but it also increases the life of the fluidity of molten metal.

35. Silicon ranges from 1. to 4. in foundry iron, 1. to 2.50 in Bessemer and 4. to 14. in ferro-silicon pig metal.

36. As a general thing it can be said that high silicon or ferro-silicon irons contain very low sulphur and carbon, with low and high phosphorus and manganese, according as it is contained in the ore flux and fuel. As an example, one analysis of 10 per cent. silicon iron contained .010 sulphur, .950 phosphorus, .570 manganese, and carbon about 1.40.

37. Any greater addition of silicon than sufficient to change the combined carbon to graphite, all that is possible, in aiming to obtain soft castings, can only result in making castings brittle or soft rotten.

38. Light castings have been made with silicon as low as .55 by reason of having low sulphur.

39. Silicon is the most unstable in pig metal and in foundry mixtures of all metalloids. One part of a pig bed or casting can be much higher than another. The last to solidify may often contain a greater percentage than that in the first to become solid or chilled.

40. By keeping sulphur, manganese and phosphorus constant, an increase of silicon will reduce "shrinkage," "contraction" and "chill," respectively, in varying degrees and a decrease of silicon the contrary results.

41. **Phosphorus** ranges in iron from .05 to 2.50; over .80 or under .20 causes iron to be cold short or weakens it. By keeping phosphorus at .40 to .60, with silicon at 1.70 to 2.00, sulphur not over .04 and manganese about .50 in castings, light work can often be made to twist and bend to a surprising degree.

42. Phosphorus increases the life and fluidity of iron. The greater its percentage, the greater this element is affected, but it should not be used to such a degree as to cause brittleness. Phosphorus should rarely be allowed to exceed .70 unless exceptional life or fluidity is desired.

43. Each tenth of one per cent. increase of phosphorus will give about the same results physically that an increase of one-quarter of one per cent. silicon will give, if the phosphorus is unchanged. Where sulphur is high, a rational increase of phosphorus can often soften iron or decrease its contraction.

44. Phosphorus is preferable to silicon to give fluidity or life to liquid metal. Mixtures can be regulated by reason of increasing or decreasing phosphorus similarly as by changes in silicon and sulphur.

45. **Manganese** has a great affinity for sulphur and can eliminate it almost wholly from iron, when carried

up to high percentages. It gives some life to the fluidity of iron and may soften it by reason of expelling the sulphur.

46. Increasing manganese over .70, with the other metalloids constant, enlarges the "chill," "shrinkage" and "contraction." Its general tendency is to harden iron, which will be very effective when it exceeds .75. The lighter the castings, the greater this effect.

47. Manganese ranges from .10 to 3.00, but on an average is found at about .50 in general foundry pig metal. It has been used as a physic in liquid metal, with the aim of preventing "blow holes" or assisting in producing sound castings, and increases the life of the fluidity of metal as well as the strength of iron.

48. **Aluminum** sometimes mixed in iron as an alloy cannot achieve anything in cast iron that silicon will not do, and the latter is the much cheaper element of the two.

49. **Pig metal** is classed as "foundry," "grey forge," "silvery" or ferro-silicon, "charcoal," "bessemer," "mottled," and "white iron."

50. **The way to define iron is by "grades."** It should be classed as a high grade, a middle grade or a low grade, and always bought by analysis.

51. **There is no "bad iron" or "good iron."** There are specialties in which all kinds of iron can be well utilized. An iron that might be ill-suited for one class of work could be excellent for another.

52. **"Foundry iron"** is made with coke or anthracite fuel; its silicon ranges from .75 to 3.50; sulphur, .01 to .05; phosphorus from .2 to 1.25; manganese from .30 to 1.00, and is a class of iron used in the construction of chilled as well as unchilled work in general founding.

53. **"Grey forge iron"** is pig metal very low in silicon, generally not exceeding 1.00. It is the cheapest iron made. It is often derived from low grades of foundry iron, by reason of a furnace working cold. Its sulphur is generally very high, sometimes reaching .10 and over in the pig metal. It may also be high in phosphorus and manganese. This class of metal is chiefly used as mill iron in puddling furnaces to produce wrought iron, and for the manufacture of pipes, etc., when mixed with higher silicon irons, also alone for castings in which high shrinkage and contraction or slight hardness may not be objectionable.

54. **"Silvery iron," or ferro-silicon,** is sometimes made with all coke, and then again with coal and coke mixed. The silicon ranges from 3.50 to 14.00 in such irons. It requires high temperatures to make it, and it is derived from extra fuel over that used for making coke or anthracite iron.

55. **"Bessemer"** is made with coke and coal, its silicon ranging from .75 to 2.50, sulphur .01 to .05; phosphorus must never exceed .10. If the iron exceeds this in phosphorus it is then called "off Bessemer" or may be run in as "foundry." Its manganese ranges from .30 to .60. This iron is chiefly used for making steel and ingot moulds and can often be well used to take the place of "foundry."

56. **"White" and "mottled iron"** has silicon .25 to 1.00; sulphur from .050 to .150; phosphorus, .10 and upward; manganese, .30 to 1.00 or over. These irons are generally the off product of a furnace that had not been working well and are generally used for making hard castings or for mill purposes to be mixed with grey forge.

57. **Charcoal iron** is made with charcoal fuel. Its silicon generally ranges from .60 to 2.00; sulphur, only a trace, seldom running over .002 to .004; phosphorus, .15 to .25; manganese, .40 to 1.00; graphite and combined carbon 3 to 3½ per cent.

58. Charcoal iron, on the whole, is richer in "iron" and poorer in silicon and phosphorus as well as sulphur than a coke or anthracite pig metal. It is chiefly used for the manufacture of guns and chilled castings. For this kind of work it can excel all other classes of iron when it is melted in an "air furnace."

59. Melting charcoal iron in a cupola deteriorates its value. This can cause it to be no better than coke or anthracite, but if melted in an air furnace it can surpass other irons in producing the best strong machinable castings or iron for chilling purposes.

60. **In making chilled work** it is essential to understand the various effects which the different metalloids have in controlling the combined carbon, as the higher the combined carbon the deeper can castings chill.

61. The elements to increase combined carbon are high sulphur, manganese and low silicon.

62. In a general way it can be said that the percentages of the metalloids which combine to make chill castings range in silicon from .50 to 1.10; manganese from 0.55 to 1.50; phosphorus, .2 to .7, and sulphur from .02 to .10, with the total carbon as high as it can be secured.

63. Like depths of chill or "white iron" do not present like degrees of hardness. Variation in the sulphur, manganese and phosphorus are chief in giving a special character to the hardness of a chill.

64. The durability of chilled work is often more

dependent upon the degree of hardness of the chill than upon its depth.

65. A chill chiefly promoted by manganese will prove more yielding to strains and not so liable to "chill crack" the surface in casting or from "heat wear" in use as a chill that has been chiefly promoted by sulphur, but for "friction wear," as in the case of the tread of car wheels, sulphur gives better life than manganese.

66. Degrees of fluidity, thickness of the casting (also the thickness of chill mould used, to a limit), have all an influence independent of each other in affecting the depth of chilling, and a "hot" iron will chill deeper than a "dull" one; also a heavy casting will chill less than a light one.

67. Any casting will show a deeper chilling and "deadened back" by remaining close in contact with its chill until all the metal in the casting has solidified or become nearly cold than if the union of the casting and chill were broken before this had occurred.

68. In judging the grade of old chilled castings to be used as scrap, such as car wheels, plow points, etc., for mixture with pig metal, the texture of the grey body should be considered, as well as that of the chill.

69. **The best strengths of cast iron** are obtained (where the "metallic iron" is high up to its best limit) by securing high combined carbon, without such being wholly caused by high sulphur, manganese or low silicon. Such combinations are difficult and almost impossible to be obtained other than in an "air furnace."

70. **In re-melting iron** in an air furnace there is a chance to change its grade in the liquid metal slightly

before tapping the metal, but with cupola work this is not permissible.

71. **In a general way** it may be said that, in re-melting iron, the silicon, manganese and graphitic carbon are decreased, while the sulphur, phosphorus and combined carbon are increased.

72. The average loss of silicon by re-melting is two-tenths of one per cent.; the higher the heat and the more blast the greater the loss. The higher the silicon or graphite the higher temperature required to melt iron. Hard grades of iron will melt more easily or become fluid with less heat than soft grades.

73. The higher the sulphur in fuel, or the more used, the greater it is absorbed by the iron up to its limit of absorption. Every re-melt with fuel containing about .80 in sulphur closely doubles that originally in the iron before being charged. Sulphur in fuel can range from .60 to 1.50. It is best kept below .84.

74. **The greatest economy in fuel** is obtained where the weight of "heat" permits running cupolas to their utmost capacity, and where they have high charging doors, combined with "center blast," wherever conditions permit the application of the latter to be practical.

75. There is no economy in fuel in not using sufficient to melt down good "hot iron."

76. "Dull iron" at any part of a "heat," or the whole of it, generally implies that more fuel is required at that point or throughout the "heat." Excessively "hot iron" with slower melting generally signifies excessive fuel at whatever part of a "heat" this may be obtained.

77. A moist atmosphere will require more fuel than a dry one to obtain like fluidity, in different heats.

78. **The more even and mild the volume of blast** necessary to the combustion of fuel, and the more uniformly distributed throughout a cupola, the greater economy is obtained in all that relates to its workings and extension of "heats." It requires about 33,000 cubic feet of air to melt one ton of iron in a cupola.

79. **The amount of flux** necessary to be used is dependent upon the character of the iron, fuel used, weight of heat, and the nature of the flux.

80. As a general thing it requires a higher temperature to fuse a flux than iron. The slag produced requires the heat of from 2,000 to 3,000 degrees F. to fuse it. A flux that will work well in a blast furnace can often be well utilized in a cupola.

TESTING CAST IRON.

81. **Transverse or tensile tests can only be comparative.** Castings being generally subjected to transverse and crushing strains, the transverse test with its accompaniment, "deflection," is as a general thing better adapted to record the strength, elasticity, or resilience and rigidity of cast iron.

82. **Always use a test bar sufficiently large** so as not to be sensitively affected by the damp sand which composes green sand moulds. Many tests have proven that a test bar, to make the best or reliable comparisons in mixtures or to obtain the strength of iron, should not be any smaller in area than one square inch.

83. **For making comparative tests** of one or more grades of iron, no size of a bar should be used that will not record a strength to fairly agree with the commercial value generally known to be attached to the different grades of iron, or establish a relation between the physical test and the analysis of iron.

84. **Standards for comparative tests** are best confined to three sizes of bars, consisting of 1 1/8, 1 5/8 and 1 15/16 inches diameter and cast on end, to be broken on supports 12 inches apart. Whatever size of these bars is used in one "grade," it must be used in all others, for the reason it is not practical to define where to leave off with one and take up another, if fair or true comparisons are to be made.

85. **Thin bodies have greater strength than thick ones** of like widths, per square inch, when poured with the same iron, and the best limit for combined carbon to attain strength is not overreached in the thin body.

86. **Test bars should never be cast flat,** but cast on end, for reasons embodied in the question of radiation, uniformity in the grain and the difference which casting flat can cause in making one side of a bar stronger than the other.

87. **Avoid using test bars possessing corners,** for the reason that they are higher in combined carbon or density in grain at the corners than will be found in the balance of the outer body or shell. The round form is a common-sense bar, as it gives a uniformity of structure in its grain best calculated to give the truest comparison of mixtures or strength of iron.

88. **The contraction of a test bar** assists in defining the "grade" of an iron and nothing more. To define the silicon or any other metalloid contents of a test bar or casting a chemical analysis is necessary.

89. **The same speed in testing** should always be maintained as far as possible, as whether a bar is broken fast or slowly can make a difference in results. A micrometer should be used to measure the area of a bar at its point of fracture. Common rule measure-

ment can deceive a tester one hundred to four hundred pounds in recording the true strength.

90. **Tests of American irons range** from 1,000 to 4,000 pounds transverse strength, taken with bars of 1 square inch area, supports 12 inches apart, and from 700 to 40,000 pounds tensile strength per square inch. In "chilling" strong irons, the chilled parts can often be as strong in the direction of the chill crystals as in the gray body of the iron.

91. **Cast iron expands at the moment of solidification.** This enlarges the body of the cooling crust of a casting, leaving a void space in the interior of the parts to solidify last, and if it is not filled with a fresh supply of metal by means of "feeding," shrink holes will exist in the heavy portions and often where they join the light ones in castings.

92. A hard iron expands more than a soft one, hence the greater "shrinkage" and "feeding" found necessary in practice for hard grades of iron.

93. A heavy body expands more than a light one, thus assisting to exact a great amount of "feeding" in massive work.

94. Expansion can be suppressed in some direction by force, but the more this is retarded the less the shrinkage and the greater the contraction.

95. Decrease in volume requiring "feeding," while the metal is still liquid, is "shrinkage." Decrease in volume which takes place after the metal has solidified with the iron cooling down to atmospheric temperature is "contraction."

96. The less the expansion in like sizes, and the greater the formation of graphite, the less the contraction. In this lies the secret of light castings con-

tracting more than heavy ones; also why soft irons contract less than hard ones.

97. **Molten iron is of lighter specific gravity than solid cold iron** of the same grade and will not float its cold iron until after being heated, while solid iron of a greater density in grade than molten metal, such as liquid No. 1 iron and cold "white" iron,—the latter would sink in its bath and stay under the surface until melted.

98. **The specific gravity** of the upper and lower ends of long castings poured in a vertical position exhibit practically no difference, thus making it possible to use test bars, etc., cast on end without finding them stronger, etc., at one height than another.

99. **Cast iron can be slightly stretched** after solidification, from a point about 1,600 degrees F, down to 1,200 degrees F. in cooling. This element saves many castings from cracking or being pulled apart, etc., by the walls of rigid cores or projections of extended length in a mould, etc.

100. **The strength of unchilled** cast iron is improved by "tumbling." Castings subjected to shock or jars, such as guns, etc., should never be radically tested at first to the full severity of intended actual service, and also in "tumbling" light castings easily broken, it is best to start slowly, increasing the speed to the end, wherever this is practical.

TABLE 63.—NET WEIGHT OF IRON IN GROSS (2,268 LBS.) TONS.

Net.	Gross.	Net.	Gross.	Net.	Gross.
1	2,268	35	79,380	69	156,492
2	4,536	36	81,648	70	158,760
3	6,804	37	83,916	71	161,028
4	9,072	38	86,184	72	163,296
5	11,340	39	88,452	73	165,564
6	13,608	40	90,720	74	167,832
7	15,876	41	92,988	75	170,100
8	18,144	42	95,256	76	172,368
9	20,412	43	97,524	77	174,636
10	22,680	44	99,792	78	176,904
11	24,948	45	102,060	79	179,172
12	27,216	46	104,328	80	181,440
13	29,484	47	106,596	81	183,708
14	31,752	48	108,864	82	185,976
15	34,020	49	111,132	83	188,244
16	36,288	50	113,400	84	190,512
17	38,556	51	115,668	85	192,780
18	40,824	52	117,936	86	195,048
19	43,092	53	120,204	87	197,316
20	45,360	54	122,472	88	199,584
21	47,628	55	124,740	89	201,852
22	49,896	56	127,008	90	204,120
23	52,164	57	129,276	91	206,388
24	54,432	58	131,544	92	208,656
25	56,700	59	133,812	93	210,924
26	58,968	60	136,080	94	213,192
27	61,236	61	138,348	95	215,460
28	63,504	62	140,616	96	217,728
29	65,772	63	142,884	97	219,996
30	68,040	64	145,152	98	222,264
31	70,308	65	147,420	99	224,532
32	72,576	66	149,668	100	226,800
33	74,844	67	151,956		
34	77,112	68	154,224		

TABLE 64.—TABLE OF CHEMICAL SYMBOLS AND ATOMIC WEIGHTS.

(MEYER & SEUBERT.)

Aluminum, Al.	27.04	Lead, Pb.	206.39
Antimony, Sb.	119.6	Litharge, PbO.	
Arsenic, As.	74.9	Magnesium, Mg.	23.94
Bismuth, Bi.	207.5	Manganese, Mn.	54.8
Bromine, Br.	79.76	Mercury, Hg.	199.8
Cadmium, Cd.	111.7	Nickel, Ni.	58.6
Calcium, Ca.	39.91	Nitrogen, N.	14.01
Carbon, C.	11.97	Oxygen, O.	15.96
Carbon Graphitic, C (Graph.)		Palladium, Pd.	106.2
Carbon Combined, C (Comb.)		Phosphorus, P.	30.96
Carbonic Acid, CO_2.		Phosphoric Acid, P_2O_5.	
Carbonic Oxide, CO.		Platinum, Pt.	194.3
Chlorine, Cl.	35.37	Potassium, K.	39.03
Chromium, Cr.	52.45	Silicon, Si.	28.0
Cobalt, Co.	58.6	Silver, Ag.	107.66
Copper, Cu.	63.18	Sodium, Na.	22.995
Fluorine, F.	19.06	Sulphur, S.	31.98
Ferric Oxide, Fe_2O_3.		Tin, Sn.	117.35
Ferrous Oxide, Fe. O.		Tungsten, Wo.	183.6
Gallium, Ga.	69.9	Uranium, Ur.	239.8
Gold, Au.	196.2	Vanadium, V.	51.1
Hydrogen, H.	1.	Yttrium, Y.	89.6
Iodine, I.	126.54	Zinc, Zn.	64.88
Iridium, Ir.	192.5	Zirconium, Zr.	90.4
Iron, Fe.	55.88		

TABLE 65.—VALUE IN DEGREES CENTIGRADE FOR EACH 100 DEGREES FAHRENHEIT.

Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
100	55.56	1000	555.56	2000	1111.11	3000	1666.67
200	111.11	1100	611.11	2100	1166.67	3100	1722.22
300	166.67	1200	666.67	2200	1222.22	3200	1777.78
400	222.22	1300	722.22	2300	1277.78	3300	1833.33
500	277.78	1400	777.78	2400	1333.33	3400	1888.89
600	333.33	1500	833.33	2500	1388.89	3500	1944.44
700	388.89	1600	888.89	2600	1444.44	3600	2000.00
800	444.44	1700	944.44	2700	1500.00		
900	500.00	1800	1000.00	2800	1555.55		
		1900	1055.55	2900	1611.11		

"*Absolute Zero*" of the Air Thermometer is equal—460° Fahrenheit.
" " " " " —273.5° Centigrade.

UNITS OF HEAT.

BRITISH THERMAL UNIT.—The quantity of heat necessary to raise one pound of water through one degree Fahrenheit.

CALORIE.—The quantity of heat to raise one kilogram of water through one degree Centigrade.

Many adopt as Thermal Unit or Calorie the quantity of heat necessary to raise one pound of water one degree Centigrade, which we have adopted also in these tables.

TABLE 66.—HEAT OF COMBUSTION.

Heat developed by combustion of one pound of the following substances:

Substance.	Calories.	Substance.	Calories.
Anthracite	7,200 to 8,200	Lignite	4,500 to 6,000
Alcohol	7,185	Manganese to MnO	1,723
Carbon to CO	2,404	Marsh Gas	13,063
Carbon to CO_2	8,080	Olifient Gas	11,858
Coal—bituminous	6,500 to 9,000	Olive Oil	9,860
Coke	6,400 to 8,000	Petroleum	10,600 to 11,000
Diamond	7,879	Phosphorus—P_2O_5	5,747
Ether	9,028	Silicon	7,830
Hydrogen	34,462	Sulphur to SO_2	2,162
Iron to FeO	1,351	Sulphur SO_3	2,868
Iron to Fe_2O_3	1,887	Wood	2,500 to 4,000

TABLE 67.—SCALE OF TEMPERATURES BY COLOR OF IRON.

Dark red, hardly visible	970° F.	Orange	2000° F.
Dull red	1300° "	Yellow	2150° "
Cherry, dark	1450° "	White heat	2350° "
" red	1650° "	" welding	2600° "
" light	1800° "	" dazzling	2800° "

TABLE 68.—MELTING POINTS OF METALS.

	Cent.	Fahr.		Cent.	Fahr.
Aluminum	850	1,562	Iron	1,590	2,894
Antimony	441	826	Lead	330	626
Bismuth	266	511	Manganese	1,550	2,822
Cadmium	321	610	Nickel	1,450	2 642
Cromium	1,700	3,092	Palladium	1,500	2,732
Cobalt	1,500	2,732	Platinum	1,775	3,227
Copper	1,054	1,929	Silver	954	1,749
Gold	1,147	2,097	Tin	230	446
Iridium	1,950	3,542	Zinc	427	801

TABLE 69.—RELATIVE CONDUCTIVITY OF METALS FOR HEAT AND ELECTRICITY.

Metal (in vacuo).	Heat.	Electricity.	Metal (in vacuo).	Heat.	Electricity.
Silver	100.	100.	Iron	11.9	14.44
Copper	74.	77.43	Steel	10.3	
Gold	54.8	55.19	Lead	7.9	7.77
Zinc	28.1	27.39	Platinum	9.4	10.53
Brass	24.0	22.0	German Silver	6.3	6.
Tin	15.4	11.45	Bismuth	1.8	1.8

SPECIFIC GRAVITY of a substance is the ratio of the weight of unit volume of the substance to the weight of the same volume of water at 4°C.

DENSITY of the substance is measured by the number of units of mass in a unit volume of the substance.

TABLE 70.—SPECIFIC GRAVITY AND WEIGHT PER CUBIC INCH—METALS.

Metal.	Sp. Grav.	Weight per cu. in. lbs.	Metals.	Sp. Grav.	Weight per cu. in. lbs.
Aluminum	2.56-2.67	.094	Manganese	8.01	.200
Antimony	6.71	.242	Magnesium	1.74	.062
Bismuth	9.9	.357	Mercury	13.59	.491
Brass	7.8-8.8	.281-.310	Nickel	8.7	.314
Bronze	8.7	.314	Palladium	11.4	.411
Copper, cast	8.79	.317	Platinum, rolled	22.07	.798
Copper, wire	8.89	.322	Platinum, cast	20.33	.735
German Silver	....	....	Silver	10.5	.380
Gold, hammered	19.40	.701	Sodium	.97	.035
Gold, cast	19 26	.697	Steel	7.82	.283
Iron, cast	7.20	.260	Tin	7.29	.263
Iron, bar	7.79	.282	Zinc	6.86	.248
Lead	11.37	.411			

TABLE 71.—ULTIMATE RESISTANCE TO TENSION IN POUNDS PER SQUARE INCH.

METALS.

	Average.
Brass—cast	17,000
wire	48,000
Copper—cast	19,000
sheet	32,000
wire	61,000
Iron—cast	10,000 to 40,000
wrought	48,000 to 54,000
wire	70,000 to 90,000
Lead—cast	1,200
sheet	3,000
Platinum—wire	53,000
Steel	60,000 to 120,000
Tin—cast	5,000
Zinc	7,000 to 8,000

WOODS.

TIMBER (SEASONED).

	Average.
Ash	16,000
Beech	12,000 to 18,000
Hickory	11,000
Oak—American	11,000 to 18,000
Pine— " white and red	10,000
Poplar	7,000

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*Where cuts in this work are from drawings, the originals were made by the author.